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Early Devonian organic-walled phytoplankton from the Ponta Grossa Formation, Paraná Basin, Brazil

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Abstract

The depositional succession of the Ponta Grossa Formation (Paraná Basin) corresponds to a wave-dominated shallow-marine environment, represented by four coarsening-upwards cycles, limited by flooding surfaces. Previous studies on a well-preserved and diverse assemblage of miospores indicated a late Pragian to possibly middle Emsian age. The palynological analysis of the Jaciara section is completed herein with the analysis of the marine fraction, composed of highly abundant and diverse organic-walled phytoplankton, with 222 species recognized. Preservation and abundance of some species, that were previously informally described or mentioned, are here formally described. Additionally, two new species are instituted: *Pterospermella jaciarence* sp. nov. and *Florisphaeridium brasiliensis* sp. nov. The phytoplankton species, such as *Bimerga paula*, *B.* sp. aff. *B. bensonii*, *B. nuda*, *Condylesia oriental*, *C. uruguayensis*, *Palacanthus ledanoisii*, *Pyloferites escobaides*, *P. paranaensis* and *Winwaloeusia distracta*, recorded in the lower part of the section, indicate a late Pragian age, in coincidence with the miospore age. *Navifusa* spp. and *Pterospermella pernambucensis* first appear in the middle part of the studied section, suggesting an Emsian age, as do the miospores. The diversity and preservation quality of the phytoplankton tend to decrease towards the top of the section, probably related to a general shallowing trend.

Keywords: Phytoplankton; Taxonomy; Pragian; Emsian; Paraná Basin; Brazil.

1. Introduction

Detailed palynological papers are nowadays scarce and devalued, while papers trying to integrate the information to make regional or global climatic, evolutionary, and palaeobiogeographic interpretations are taking place. Although, meticulous systematic and taxonomic works are needed to have proper data for accurate interpretation. Devonian palynomorphs from the Paraná Basin have been studied over the last 30 years, mainly focusing on the miospore diversity and its biostratigraphic usefulness (e.g., Loboziack et al., 1988; Dino et al., 1995; Dino, 1999; Mendlowicz Mauller et al., 2007, 2009). However, because of the wide extension of the basin, added to its intracratonic nature, which in general allows good fossil preservation, there is still more research to be done. Moreover, the Devonian stratigraphic framework of the Paraná Basin is still controversial (Rodrigues de Vargas et al., 2020 and references therein). García Muro et al. (2020) published the miospore assemblage recorded from the Jaciara section, located in the northern part of the Paraná Basin, suggesting a late Pragian to possibly middle Emsian age. Such young age was proposed for the first time for the Ponta Grossa Formation. The extremely diverse and exceptionally well-preserved phytoplankton assemblage from the same section is here presented. The biostratigraphic distribution of the phytoplankton is correlated with the miospore biozones described for Gondwana.

1.2.Geological setting and the Jaciara section

The Paraná Basin is a vast intracratonic basin (Fig. 1), located in southern Brazil, east Paraguay, northern Uruguay and northeastern Argentina, encompassing an area of approximately 1.7 million km^2 (Milani et al., 2007), including sediments deposited from the Ordovician through Neogene, with a maximum thickness of 5000-7000 m in the axial portion of the basin (Piccirillo et al., 1988; Milani and Filho, 2000). The Devonian sediments of the Paraná Basin have been divided into two sub-basins because of their different sedimentological histories during most of this period: the Apucarana at the south and the Alto Garças at the north, forming two depocenters, divided by the transbrazilian lineament, with NE-SW direction (Pereira, 2000). Grahn et al. (2000) also proposed a Western Paraguay Sub-basin.

The basin was filled with six second-order depositional sequences or supersequences. Among them, the Paraná Supersequence includes Devonian deposits (Milani et al.,

2007), which are divided into the upper part of the Furnas Formation, the Ponta Grossa Formation, and the São Domingos Formation at the southern Apucarana sub-basin (Fig. 2). At the norther-shallower Alto Garças Sub-basin, the Chapadas Group Units 2-4 are coeval to the southern São Domingos Formation (Grahn et al., 2010). Although, some authors consider the São Domingos deposits as the upper member of the Ponta Grossa Formation (e.g., Henrique-Pinto et al., 2021 and references therein).

During the Pragian-early Emsian there was a regional regression system, registered in southern Bolivia and northern Argentina, and with less intensity in western Argentina (Bustos and Astini, 1997; Albariño et al., 2002; Alvarez et al., 2004; Dalenz Farjat et al., 2019), followed by a global sea-level rise during the Eifelian-Givetian periods (Chlupác and Kukal, 1988; Troth et al., 2011; Horodyski et al., 2014). Rodrigues de Vargas et al. (2020) suggested that the evolution of the Paraná Basin was mainly affected by tectonism, rather than eustatic changes, causing high-frequency periods of regressive and transgressive episodes during the Early Devonian. This caused flooding events at a regional level, embracing different basins at SW Gondwana, affecting their sedimentary supplies and erosional rates.

The contact of the Ponta Grossa Formation with the underlying Furnas Formation is abrupt, mainly in the northern part of the basin (Pereira, 2000). The sandstones of a shallow environment represented in the upper part of the Furnas Formation, are conformably overlaid by thinner sediments of a lower shoreface to offshore deposits of the Ponta Grossa Formation (Pereira, 2000; Gerrienne et al., 2001).

The Ponta Grossa Formation at the Jaciara section denotes three facies associations: weak to moderate bioturbated siltstones with wavy-lined stratification; laminated black shales and siltstones, rarely bioturbated; and medium to fine-grained sandstones with wave-cross stratification. The sandy strata present either cross-lamination structure or frequently, hummocky cross-stratification. The facies are organized in four metric coarsening - upwards cycles (PSI, PSII, PSIII and PSIV, see Fig. 3) limited by flooding surfaces, deposited in a shallow platform environment, in a progressive flooding model (García Muro et al., 2020 and references therein).

2. Materials and methods

A total of 27 samples were analyzed, that come from an outcrop (Fig. 3) situated at 5 km west from the town of Jaciara, Mato Grosso, Brazil (15° 58′ 37,6” S; 55° 00′ 31,9” W). Samples were processed at the University of Liège, EDDy (Evolution & Diversity

Dynamics) Lab/palynology laboratory, Belgium, using standard HCl–HF– HCl acid-maceration techniques (Traverse, 2007). The residues were oxidized with a Schulze solution (HNO_3 +$KClO_3$) and then, screened on a 12 μm sieve. The palynological slides are housed in the EDDy Lab/Palynology. Slides were examined using light microscopy with interference contrast. Specimen locations are referred to by using England Finder coordinates, indicated between brackets.

The organic-walled phytoplankton is listed in the Systematic section according to the classification proposed by Le Hérissé et al. (2009). Some remarks are provided in cases of doubtful assignments or differences with the original diagnosis of the species. Descriptions of new species are also given, especially for those species that were not validly published (e.g., in theses or conference proceedings) and were subsequently mentioned in palynological contributions as *nomen nudum*.

Around 300 palynomorphs were counted per slide to obtain the relative abundance of marine and terrestrial palynomorphs throughout the studied section. The organic matter counted was: miospores, chlorophytes, marine acritarchs, non-marine palynomorphs, cuticles, phytoclasts and possible palynomorph remains. The organic matter data were related to the geochemical data published in García Muro et al. (2020).

3. Results and Discussion

The Jaciara section yields the most diverse phytoplankton assemblage described hitherto from the Devonian of Brazil, with a total of 222 species. A detailed counting of all palynomorphs reveals that the marine fraction represents, in most of the samples, more than 50% of the assemblage, mainly coinciding with the flooding surfaces at the beginning of each cycle (Fig. 3). PS I, PS II and the lower part of PS III, present major abundance of acritarchs, followed by prasinophytes and phytoclasts. This portion also corresponds to the high values of δ^{13}Corg (see García Muro et al., 2020), related to greater contribution from land plants (Chen et al., 2017), that would be associated in this case with the phytoclasts. Besides, the sandier deposits of PS I and II are strongly related to the forced regression episodes during the Early Devonian transgression (García Muro et al., 2020). Samples corresponding to the rest of the cycle PS III and PS IV, including the black shales flooding surface, contained a high abundance of acritarchs, followed by fluctuating abundances of trilete spores and phytoclasts. This matches with high values of TOC and negative δ^{13}Corg values, associated with the flooding surfaces (Dias and Rodrigues, 2006). Since the middle part of the PS III, the

increase of phytoclasts and trilete spores, could indicate a general shallowing trend towards the top of the Jaciara section. Otherwise, the presence of terrestrial organic material in relatively distal marine facies could also be related to climatic conditions, such as humid periods that increased nutrient input to the sea (García Muro et al., 2014). The complete list of phytoplankton species is given below. Description and remarks are provided for unidentified phytoplankton (if necessary) or when differences with the original diagnoses of the species were observed. The corresponding illustrations are shown in Plates I-IX Their stratigraphic distribution is detailed in Figures 4-7.

Systematic palaeontology

Marine Chlorophytes

Prasinophytes

Genus ***Cymatiosphaera*** Wetzel ex Deflandre 1954

Type species: *Cymatiosphaera radiata* O. Wetzel 1933

Cymatiosphaera acinosa Wicander 1974. Plate I, 1

Cymatiosphaera daioariochora Wicander 1974. Plate I, 2

Cymatiosphaera cf. *jardinei* Cramer and Díez 1976. Plate I, 3

Cymatiosphaera lawsonii Mullins 2001. Plate I, 4

Cymatiosphaera aff. *ledburiea* Dorning 1981 in Mullins (2001). Plate I, 5

Cymatiosphaera mariae Cramer et al. 1976. Plate I, 6

Cymatiosphaera mirabilis Deunff 1959. Plate I, 7

Cymatiosphaera multiseptа Deunff 1955. Plate I, 8

Cymatiosphaera nebulosa (Deunff) Deflandre 1954. Plate I, 9

Cymatiosphaera cf. *nimia* Le Hérissé 2002. Plate I, 10

Cymatiosphaera octoplana Downie emend. Mullins 2001. Plate I, 11

Cymatiosphaera paucimembranae Mullins 2001. Plate I, 12

Cymatiosphaera peligrosa Cramer 1964. Plate I, 13

Cymatiosphaera perimembrana Staplin 1961. Plate I, 14

Cymatiosphaera prismatica Deunff ex Deunff 1961. Plate I, 15

Cymatiosphaera rhacoamba Wicander 1974. Plate I, 16

Cymatiosphaera tryphera Wicander and Wood 1981. Plate I, 17

Cymatiosphaera velicarina Wicander 1974. Plate I, 18

Cymatiosphaera winderi Deunff emend. Playford 1977. Plate I, 19

Cymatiosphaera sp. in Rubinstein et al., 2017. Plate I, 20

Cymatiosphaera sp.1. Plate I, 21

Description: vesicle circular in outline, wall of 2 μm thick, surface levigated or striated, divided by membranes into few (four or five) large polygonal fields per hemisphere. The base of the membranes has folds and the junction of the membranes is higher than the middle part.

Dimensions: 60-65 μm in diameter, membrane of 3-4 μm high and up to 6 μm high in the junction of the membranes. Fields of 30 μm width. 3 measured specimens.

Remarks: Few specimens were recorded, hindering the creation of a new species. *Cymatiosphaera canadensis* Deunff 1961 is smaller (45 μm) and have more fields per hemisphere.

Cymatiosphaera spp.

Genus ***Dictyotidium*** Eisenack emend. Staplin 1961

Type species: *Leiosphaera dictyota* Eisenack, 1938

Dictyotidium variatum Playford 1977. Plate I, 22

Dictyotidium spp. Plate I, 23

Genus ***Melikeriopalla*** Tappan and Loeblich emend. Mullins 2001

Type species: *Melikeriopalla amydra* Tappan and Loeblich 1971

Melikeriopalla fissura (Tappan and Loeblich) Mullins 2004. Plate I, 24

Genus ***Pterospermella*** Eisenack, 1972

Type species: *Pterospermopsis aureolata* Cookson and Eisenack, 1958

Pterospermella brasiliensis (Brito) Eisenack et al. 1973. Plate I, 25

Pterospermella circumstriata (Jardiné et al.) Eisenack et al. 1973. Plate I, 26

Pterospermella crassimarginata sp. nov. Plate I, 27-30

Etymology: From latin, crassi: thick, marginata: margin.

Locality: 5 km west from the town of Jaciara, Mato Grosso, Brazil.

Holotype: Plate I, fig. 27, specimen 15-61682 (D39/2).

Paratype: Plate I, fig. 28, specimen 19-61690 (U34).

Synonymy

1991 *Pterospermella crassimarginata* sp. n. Oliveira: p. 62, Plate 2, figs. 9-13. Nomen nudum

1997 *Pterospermella crassimarginata* Oliveira and Burjack (in press) Oliveira: p. 92, Plate 14, fig. 2-3.

2001 *Pterospermopsis crassimarginata* Le Hérissé: pp. 118-120 (not illustrated).

2007 *Pterospermella crassimarginata* Mendlowicz Mauller et al.: p. 10, fig. 10, 11.

2018 *Pterospermella crassimarginata* Trindade and de Araujo Carvalho: p. 79 (not illustrated).

Studied material: 2-61655 (P51/1), 2-61655 (W32/4), 2-61655 (T28/4), 2-61655 (K28/4), 3-61658 (T23/2), 4-61660 (D36/2), 5-61836 (S51/1), 5-61836 (G45/1), 6-61664 (V40/1), 8-61668 (N47/4), 9-61840 (Q49/4), 10-61841 (M29/2), 11-61674 (K23), 12-61676 (V25/1, W25/1), 13-61844 (T43/1), 14-61680 (R41), 15-61682 (D39/2), 16-61684 (O41), 17-61686 (T33), 18-61688 (M40/2), 19-61690 (U34, U24/3, V37/3), 20-61692 (L38/4), 25-61702 (F41/1).

Diagnosis and description (not validly published in Oliveira, 1991): Vesicle circular to subcircular in outline, with a central body surrounded by an equatorial radiated membrane. The central body wall is thin and reticulated. The reticulum is clearly distinguished, presenting polygonal lacunas with well-defined muri. The equatorial margin of the central body is thick (3 µm), easily observed. The internal outline of the margin is smooth or lobed. The equatorial membrane is smooth or slightly granulated. This membrane seems to be sustained by several rays that irradiate from the equatorial margin of the central body. The rays extend throughout the entire membrane, they can emerge close to each other, with their bases almost joined or separated by 9-12 µm. The proximal part of the rays is relatively wide (2-3 µm), becoming thinner towards the edge of the membrane. Excystment opening by a simple split in the central body. (Translated from the Portuguese).

Description: Vesicle circular in outline, wall thin and reticulated, frequently with a fold in the middle part. The equatorial margin of the vesicle presents a 3-5 µm thickening. The internal side of the thickened margin is smooth or lobed. The equatorial membrane is thin, with folds that may radiate below the equatorial thickness, or from the external part of the central body. The numerous folds, widened at their base, are close or even joined together. The membrane's width is not proportional to the vesicle diameter.

Dimensions: Vesicle 42 (55) 75 μm, membrane 13-20 μm width. 24 specimens measured.

Comparison: Pterospermella brasiliensis (Brito, 1967) Eisenack et al., 1973 is smaller, and presents a fine striation that radiates from the central zone of the vesicle. The original description of *P. brasiliensis* does not mention the thickened margin of the vesicle, nor does it mention a reticulated vesicle wall.

Distribution: Frasnian, Paraná Basin (Oliveira, 1991); middle Givetian -Early Famennian, Paraná Basin (Oliveira, 1997); Early Frasnian, Amazon Basin, Brazil (Le Hérissé, 2001); Lower Devonian of Paraná Basin (Mendlowicz Mauller et al., 2007); Upper Devonian of the Parnaíba Basin, Brazil (Trindade and de Araujo Carvalho, 2018, not illustrated).

Discussion: The species was described by Oliveira (1991) in her master thesis. The taxon is also mentioned as a new species, presented in the abstract of a dissertation during the XII Congresso Brasileiro de Paleontologia (Oliveira and Burjack, 1991). According to the PhD thesis of Oliveira (1997), the species was published by Oliveira and Burjack (1997), in the Anais of the 36 Brazilian Palaeontological Congress, which is not available. Afterwards, it was recognized in some Brazilian palynological assemblages as *nomen nudum* (see synonymy list). According to the ICBN, descriptions of new species in thesis and congresses are not valid. We recognized the species in several samples from the Jaciara section, thus, we find it valuable to validly describe *Pterospermella crassimarginata* as a new species.

Pterospermella elliptica Pöthé de Baldis 1981. Plate II, 1

Pterospermella guapiara (Cramer) Eisenack et al. 1973. Plate II, 2

Pterospermella cf. *latibalteus* Wicander 1974. Plate II, 3

Pterospermella cf. *martinii* (Cramer) Eisenack et al. 1973. Plate II, 4

Remarks: Specimen 22-61696 (N32/4) does not present a foveolate wall, but the characteristic ornamented excystment opening is clearly visible.

Pterospermella pernambucensis (Brito) Eisenack et al. 1973. Plate II, 5

Pterospermella cf. *radiata* Wicander 1974. Plate II, 6

Pterospermella cf. *rajada* (Cramer) Eisenack et al. 1973. Plate II, 7

Pterospermella reticulata Loeblich and Wicander 1976. Plate II, 8

Pterospermella timofeevi Deunff in Eisenack et al. 1973. Plate II, 9

Pterospermella jaciarense sp. nov. Plate II, 10-12

Etymology: It refers to the Jaciara section, where the samples were collected.

Locality: 5 km west from the town of Jaciara, Mato Grosso, Brazil.
Holotype: Plate II, fig. 10, specimen 4-61660 (R46/4)
Paratype: Plate II, fig. 11, specimen 8-61668 (J35)
Studied material: 2-61655 (G47), 3-61658 (V27/1), 3-61658 (U27/3), 3-61658 (J26/4), 22-61696 (T32/3), 22-61696 (V45/1), 22-61696 (K46), 22-61696 (Q32), 4-61660 (R46/4), 5-61662 (H47/1), 5-61662 (X42/1), 6-61664 (D47/3), 8-61668 (J35), 7-61666 (N42, P24/1, M27/2), 9-61670 (F49/1; G35; O38/1), 10-61671 (D43), 11-61674 (J31/1, E29/1, O47), 12-61676 (L50/1), 14-61680 (O44/2), 18-61688 (V28, E45/4), 19-61690 (F45/4), 21-61694 (J44/1, Q46/4), 26-61704 (E45), 27-61706 (U35/1).
Description: vesicle circular in outline, wall thick, grano-reticulate. The equatorial membrane is finely granulated, and an equatorial thicker rim of 1 μm width is often present. Some folds in the vesicle may occur.
Dimensions: Vesicle diameter 9 (17.5) 25 μm, membrane width 5-13 μm. 26 specimens measured.
Comparison: *Pterospermella occidua* Deunff (1980) does not present a granulate vesicle. *Pterospermella granulata* Al-Ameri (1984) does not present a granulate membrane, or equatorial thickening either. According to Cramer (1964) *Pterospermella hermosita* has an equatorial membrane thin and transparent. However, the specimen illustrated (Plate XVI, 12) shows a thickened rim in the distal part of the membrane, but it is not granulated.
Pterospermella spp.

Genus ***Tasmanites*** Newton 1875
Type species: *Tasmanites punctatus* Newton 1875
Tasmanites sp. Plate II, 13

Possible Prasinophytes

Genus ***Baculatireticulatus*** Al-Ameri 1984
Type species: *Baculatireticulatus baculatus* Al-Ameri 1984
Baculatireticulatus spp. Plate II, 14

Genus ***Duvernaysphaera*** Staplin emend. Deunff, 1964
Type species: *Duvernaysphaera tenuicingulata* Staplin, 1961

Duvernaysphaera angelae Deunff 1964. Plate II, 15

cf. *Duvernaysphaera stellata* Deunff 1964. Plate II, 16

cf. *Duvernaysphaera wilsonii* Deunff 1964. Plate II, 17

Genus ***Hemiruptia*** Ottone 1996

Type species: *Hemiruptia legaultii* 1996

Hemiruptia spp. Plate II, 18

Genus ***Muraticavea*** Wicander, 1974

Type species: *Muraticavea enteichia* Wicander 1974

Muraticavea munificus Wicander and Wood 1981. Plate II, 19

Genus ***Palacanthus*** Wicander, 1974

Type species. *Palacanthus acutus* Wicander 1974; by original designation.

Palacanthus ledanoisii (Deunff) Playford 1977. Plate II, 20

Palacanthus cf. *ledanoisii* (Deunff) Playford 1977. Plate II, 21

Remarks: Specimen with six processes cone-form in one plane, with their bases contiguous. It differs from other *Palacanthus* species because it has a thinner wall between the processes that reach half processes length. Their edges are straight.

Genus ***Polyedryxium*** Deunff 1954 ex Deunff 1961

Type species: *Polyedryxium deflandrei* Deunff 1954

Polyedryxium? *asperum* Cramer 1964. Plate II, 22

Polyedryxium calculosum Colbath 1990. Plate II, 23

Polyedryxium carnatum Playford 1977. Plate II, 24

Polyedryxium condensum Deunff 1971. Plate II, 25

Polyedryxium decorum Deunff, 1955. Plate II, 26

Polyedryxium? *embudum* Cramer 1964. Plate II, 27

cf. *Polyedryxium evolutum* Deunff 1955. Plate II, 28

Polyedryxium fragosulum Playford, 1977. Plate II, 29

Polyedryxium helenaster Cramer 1964. Plate II, 30

Polyedryxium multifrons Deunff 1971. Plate III, 1

Polyedryxium nudatum Deunff ex Deunff 1971. Plate III, 2

Polyedryxium pharaone Deunff, 1961. Plate III, 3

Polyedryxium simplex Deunff 1955. Plate III, 4

Polyedryxium cf. *talus* Deunff 1971. Plate III, 5

Polyedryxium spp.

Genus ***Polyplanifer*** Cramer 1964

Type species: *Polyplanifer exoticum* Cramer 1964

Polyplanifer turbatum Daners et al. 2017. Plate III, 6

Genus ***Stellinium*** Jardiné et al. 1972

Type species: *Stellinium micropolygonale* (Stockmans and Willière) Playford 1977

Stellinium micropolygonale (Stockmans and Willière) Playford 1977. Plate III, 7

Stellinium rabians (Cramer) Eisenack et al. 1976. Plate III, 8

Stellinium? *tetrahedroide* (Cramer) Eisenack et al. 1976. Plate III, 9

Marine Acritarchs

Algae Incertae sedis

Group Acritarcha Evitt 1963

Genus ***Acriora*** Wicander 1974

Type species: *Acriora petala* Wicander 1974

Acriora petala Wicander 1974. Plate III, 10

Remarks: This species is frequent in almost all samples. It differs mainly from *Diaphorochroa gracile* (also frequent in the Jaciara section) by the processes that do not communicate with the vesicle and by their shorter branches. However, such differences are not always easy to distinguish, due to the dense wall ornamentation and the wide variability of both taxa.

Genus ***Ammonidium*** Lister, 1970

Type species: *Ammonidium microcladum* (Downie) Lister 1970

Ammonidium inornatum Colbath 1990. Plate III, 11

Ammonidium maravillosum (Cramer) Thusu 1973. Plate III, 12

Ammonidium microcladum (Downie) Lister 1970. Plate III, 13

Remarks: The specimen from Jaciara coincides with the original description of *Baltisphaeridium microcladum* of Downie (1963) by the processes length (50% of the vesicle diameter) and their regularly dichotomous or trichotomous branched.
Ammonidium uncinum Loeblich and Wicander 1976. Plate III, 14
Ammonidium waldronense (Tappan and Loeblich) Dorning 1981. Plate III, 15
Ammonidium spp.

Genus ***Arkonia*** Burmann 1970
Type species: *Arkonia virgata* Burmann, 1970
Arkonia nova Le Hérissé 2002. Plate III, 16
Arkonia paulumstriata Le Hérissé 2002. Plate III, 17-18
Remarks: Specimen 11-61674 have longer processes (20-30 μm) than those of the original description by Le Herissé (2002) (5-12 μm). Both *Arkonia* species have so far only been recorded from the Silurian.

Genus ***Bimerga*** Wood emend. Daners and Le Herissé 2017
Type species: *Bimerga bensonii* Wood 1995
Bimerga acharii Daners et al. 2017. Plate III, 19
Bimerga bensonii Wood 1995. Plate III, 20-21
Remarks: The numerous specimens of *B. bensonii* recorded in the Jaciara section, show high morphological variability, here consider as intraspecific variability, as explained by Wood (1995). Thus, the specimens previously mentioned as *Bimerga* sp. *aff. B. bensonii* Wood 1995 and *Bimerga* sp. A (Mendlowicz Mauller et al., 2009; Daners et al., 2017), are here considered as *B. bensonii*, therefore extending the stratigraphic range of this species to the Pragian-Emsian.
Bimerga nuda Daners et al., 2017. Plate III, 22
Remarks: The specimen in Plate III, 22 has one extra process (four) in one extreme, instead of three as the maximum described for the species.
Bimerga paula Le Hérissé 2011. Plate III, 23
cf. *Bimerga* sp. Plate IV, 1
Remarks: It is doubtfully assigned to *Bimerga* due to the presence of a third shorter perpendicular process that also bifurcates.

Genus ***Buedingiisphaeridium*** Schaarschmidt emend. Lister emend. Sarjeant

and Stancliffe 1994

Type species: *Buedingiisphaeridium permicum* Schaarschmidt 1963, by original designation.

Buedingiisphaeridium cf. *pyramidale* Lister 1970. Plate IV, 2

Genus ***Cordobesia*** Pothe de Baldis 1977

Type species: *Cordobesia oriental* Pothe de Baldis 1977

Cordobesia oriental Pöthe de Baldis 1977. Plate IV, 3

Remarks: Some specimens recognized from Jaciara section are similar to those described by Oliveira (1997) in her PhD thesis as *Estiastra spinureticulata*, that according to the description and the illustrated specimen actually correspond to *Cordobesia oriental*.

Cordobesia uruguayensis (Martinez-Macchiavello) Pothe de Baldis 1977. Plate IV, 4

Genus ***Costatilobus*** Playford emend. Deunff 1980

Type species: *Costatilobus undulatus* Playford 1977

Costatilobus aremoricanus Deunff 1980. Plate IV, 5

Remarks: According to the original description by Deuff (1980) the processes have bifurcated branches, although the illustrated specimen denotes one process bifurcated (plate II, figs. 19-20). The processes of the specimens recorded from the Jaciara section seem to be simple. Specimen from level 11-61674 (H38/1) has one perpendicular process. Specimens are the same as that illustrated by Rubinstein et al. (2018) classified as *Costatilobus* sp. (p. 286, fig. 5.1).

Costatilobus undulatus Playford 1977. Plate IV, 6

Costatilobus spp. Plate IV, 7

Remarks: Some specimens were classified as *Costatilobus* because they have processes with enlarged base and they are striate, but the specimens could not be classified at specific level due to their preservation.

Genus ***Crassiangulina*** Jardiné et al. emend. Wauthoz et al. 2003

Type species: *Crassiangulina tesselita* Jardiné et al. emend. Wauthoz et al. 2003

Crassiangulina tesselita Jardiné et al. emend. Wauthoz et al. 2003. Plate IV, 8

Genus ***Cymbosphaeridium*** Lister 1970

Type species: *Cymbosphaeridium bikidium* Lister 1970

Cymbosphaeridium spp. Plate IV, 9

Remarks: Few specimens were classified as *Cymbosphaeridium* because of they have double-wall and the processes are tubiform, formed by the outer wall, but the specimens could not be classified at specific level because of preservation.

Genus ***Dateriocradus*** Tappan and Loeblich 1971

Type species: *Dateriocradus polydactylus* Tappan and Loeblich 1971, by original designation.

Dateriocradus tribrachiata (Lister) Dorning 1981. Plate IV, 10

Dateriocradus sp. B in Playford, 1977. Plate IV, 11

Dateriocradus sp. Plate IV, 12

Description: Vesicle triangular with a process arising from each vesicle corner and one process from the central part of the vesicle. Processes furcate distally up to 4rd order and one of the angle's processes furcates from the base.

Genus ***Diaphorochroa*** Wicander 197

Type species: *Diaphorochroa ganglia* Wicander 1974

Diaphorochroa gracile sp. nov. Plate IV, 13-16

Etymology: From latin, gracile, slender.

Locality: 5 km west from the town of Jaciara, Mato Grosso, Brazil.

Holotype: Plate IV, fig. 13, specimen 1-61654 (K40/1)

Paratype: Plate IV, fig. 14, specimen 2-61655 (P36/4)

Synonymy

1991 *Diaphorochroa gracile* Burjack and Oliveira 1990, Oliveira: p. 92, Plate 5, figs. 6 and 7 (Master Thesis). Nomen nudum.

1997 *Diaphorochroa gracile* Burjack and Oliveira (in press), Oliveira: p. 62, Plate 3, figs. 1 and 2 (PhD Thesis).

2001 *Diaphorochroa gracile* Le Hérissé: pp. 119, 121 (not illustrated).

2021 *Diaphorochroa gracile* Burjack and Oliveira *apud* Oliveira, 1997, *nomen nudum*, Steemans: p. 9, plate 2, figure 11.

Studied material: 24-61700 (Q26/1), 24-61700 (W40), 23-61698 (X40/1), 23-61854 (O49/1), 23-61696 (J40), 22-61696 (F38/4), 22-61696 (H49/2), 1-61654 (G44/4), 1-61654 (K40/1), 2-61655 (P36/4), 2-61655 (P41/2), 3-61658 (C40), 3-61834 (V51), 4-

61660 (F49/1), 4-61660 (J50/1), 5-61662 (Q44/3), 6-61664 (J34/2), 7-61666 (K30), 9-61670 (O49/3), 10-61671 (Q40), 10-61671 (J48/4), 13-61678 (X32), 14-61680 (S47-3), 15-61682 (Q35/3), 16-61684 (M24/3), 19-61690 (O38), 21-61694 (D27/3), 25-61702 (K45), 26-61704 (H44/3), 27-61706 (K45/4), 27-61706 (M41/1).

Original description (PhD Thesis, Oliveira, 1997): Vesicle originally spherical, hollow, single-walled, covered by uniformly distributed microgranules, with 6-26 homomorphic conical to cylindrical processes arranged in angular contact on the vesicle. Processes are hollow and open to the vesicle interior, with 3-4 first-order subdivisions, perpendicular to the main stem and in the same plane, at the distal end. Second-order subdivisions are frequent. The processes, including the distal branching, may be levigate or ornamented with spiny ridges helically arranged. (Translated from the Portuguese)

Diagnosis: Vesicle rounded to oval, wall densely covered by grana. Processes open into and communicate freely with vesicle interior, distally furcate, wall processes psilate to microgranulate.

Description: Vesicle rounded to oval, wall densely covered by granules, apparently thick (*c.*)1.5-2 width with 12 to 30 processes irregularly distributed, distally furcating up to second order, in aculeate branches. Processes wall thin, psilate to microgranulate, but ornamentation is much more scattered than in the vesicle's wall. Processes open into and communicate freely with vesicle interior. Excystment by a simple split.

Dimensions: Vesicle 20 (28) 50 µm, processes length 6.5 (11.5) 15, processes width 1-2 µm, branches length 1 (2) 4 µm. 30 specimens measured.

Discussion: According to the diagnosis of the genus (Wicander, 1974), the processes are levigate. However *Diaphorochroa gracile* erected by Oliveira (1997) and some specimens recovered from the Jaciara section are ornamented with spiny ridges. Oliveira (1991) in her master thesis mentions the species as published by Burjack and Oliveira (1990), but it corresponds to an abstract from a report communication of the Paleobotánica Latinoamericana, without description of the species. Afterwards, in her PhD thesis (1997), she refers to the species as in press, which corresponds to an abstract from a congress, and no formal description is made for the species either.

Diaphorochroa gracile is abundant in almost all the samples of the Ponta Grossa Formation, consequently, the species is here formalized.

Distribution: Early Frasnian, Amazon Basin, Brazil (Le Hérissé, 2001); Frasnian, Parnaíba Basin (Steemans et al., 2021), early Eifelian-late Frasnian Eifelian-Frasnian in Oliveira (1997) PhD theses.
Diaphorochroa spp.

Genus ***Diexallophasis*** Loeblich, 1970
Type species: *Diexallophasis denticulata* (Stockmans and Willière) Loeblich, 1970
Diexallophasis remota Group Mullins, 2001. Plate IV, 17
Diexallophasis simplex Wicander and Wood 1981. Plate IV, 18

Genus ***Dicommopalla*** Loeblich 1970
Type species: *Dicommopalla macadamii* Loeblich 1970
Dicommopalla sp. Plate IV, 19
Remarks: One specimen was recorded, hindering the creation of a new species. The genus has only been recorded from the Middle to Upper Ordovician (Bunner and Legault, 1989; Delabroye et al, 2011), thus, it could be reworked in the Jaciara section.

Genus ***Dorsennidium*** Wicander emend. Sarjeant and Stancliffe 1994
Type species: *Dorsennidium patulum* Wicander 1974, by original designation.
Dorsennidium cantabricum (Cramer emend. Lister) Sarjeant and Stancliffe 1994. Plate IV, 20
Dorsennidium estrellitae (Cramer) Sarjeant and Stancliffe 1996. Plate IV, 21
Dorsennidium europaeum (Stockmans and Willière) Sarjeant and Stancliffe 1994 emend. Mullins 2001. Plate IV, 22
Dorsennidium inflatum (Downie emend. Lister) Sarjeant and Stancliffe 1994 emend. Mullins 2001. Plate IV, 23
Dorsennidium polyaster (Staplin) Sarjeant and Stancliffe 1996. Plate IV, 24
Dorsennidium spp.

Genus ***Ecmelostoiba*** Wicander 1974
Type species: *Ecmelostoiba asymmetrica* Wicander 1974
Ecmelostoiba cf. *asymmetrica* Wicander 1974. Plate IV, 24
Remarks: The recorded specimen has more processes than described by Wicander (1974) (10 vs. 7).

Genus ***Estiastra*** Eisenack emend. Sarjeant and Stancliffe 1994

Type species: *Estiastra magna* Eisenack 1959

Estiastra barbata Downie 1963. Plate IV, 25

Estiastra culcita Wicander 1974. Plate IV, 26

Estiastra stellata Loeblich 1970. Plate IV, 27

Estiastra uruguaia Pöthe de Baldis 1977. Plate IV, 28

Estiastra sp. in Ottone 1996. Plate IV, 29

Estiastra spp.

Genus ***Eupoikilofusa*** Cramer 1970

Type species: *Eupoikilofusa striatifera* (Cramer) Cramer 1970

Eupoikilofusa stratifera (Cramer) Cramer 1970. Plate IV, 30

Genus ***Evittia*** (Brito) emend. Lister, 1970 emend. Sarjeant and Vavrdová, 1997

Type species: *Evittia sommeri* Brito, 1967

Evittia geometrica Playford in Playford and Dring, 1981. Plate V, 1

Evittia sanpetrensis (Cramer) Lister 1970. Plate V, 2

Evittia sommeri-Evittia geometrica Group Rubinstein et al., 2018. Plate V, 3-4

Genus ***Exochoderma*** Wicander, 1974

Type species: *Exochoderma irregularis* Wicander, 1974

Exochoderma arca Wicander and Wood, 1981. Plate V, 5

Exochoderma arca Wicander and Wood 1981-*Evittia sommeri* Brito 1967 transient forms. Plate V, 6

Remarks: Some of the Jaciara specimens are transitional forms between these two species. Both taxa have the same size, according to the original descriptions, and may have processes with short branches or simple. The main difference would be the ornamentation of the wall in *Exochoderma arca*, although it can be slightly granulate, which in specimens badly preserved is not clearly distinguishable. The transient forms between both species were already noted by Wicander et al. (2011) and Rubinstein et al. (2018).

Exochoderma irregulare Wicander 1974. Plate V, 7

Exochoderma triangulata Wicander and Wood 1981. Plate V, 8-9

Remarks: Some specimens, such as Plate V, 8, have short processes, similar to *Evittia geometrica*, but are bigger in total size.

Genus ***Filisphaeridium*** Staplin et al. emend. Sarjeant and Stancliffe 1994
Type species: *Micrhystridium setasessitante* Jansonius 1962, by original designation.
Filisphaeridium muscosum (Wicander and Playford) Sarjeant and Stancliffe 1994. Plate V, 10

Genus ***Florisphaeridium*** Lister 1970
Type species: *Florisphaeridium castellum* Lister 1970
Florisphaeridium pequenisimum Rodriguez-Gonzalez 1983. Plate V, 11
Florisphaeridium toyetae (Cramer) Cramer and Díez 1976. Plate V, 12
Florisphaeridium brasiliensis sp. nov. Plate V, 13-16
Etymology: It refers to Brazil, the country where the samples were collected.
Locality: 5 km west from the town of Jaciara, Mato Grosso, Brazil.
Holotype: Plate V, fig. 13, specimen 11-61674 (R23/4)
Paratype: Plate V, fig. 14, specimen 14-61845 (W42/2)
Studied material: 22-61696 (K36/4), 22-61696 (J43), 22-61696 (L38/4), 22-61696 (M24/3), 4-61654 (K35/4), 5-61655 (O41/3), 8-61668 (R29), 7-61666 (J49/3), 9-61670 (K47/1), 11-61674 (R23/4), 11-61674 (V37), 14-61845 (W42/2), 15-61682 (O48/4), 15-61682 (U48/4), 17-61686 (J36/4), 19-61690 (S25/3), 21-61694 (P45/1), 21-61694 (G33/1), 26-61704 (P42), 27-61706 (T28/1).
Diagnosis: Vesicle polygonal to rounded, processes generally broad-based and distally ending in a crown of spines. Distally the wall of the processes invaginates.
Description: Vesicle wall thin, smooth or micropunctate. 12- 30 broad- based processes (except for the specimen of Plate V, 15, in which their bases are slightly constrained), giving a polygonal shape to the vesicle in specimens with fewer processes. Distally the wall of the processes invaginates. Processes distally terminating in a crown of 3-5 spines.
Dimensions: Vesicle diameter 16 (18) 24.5 μm, processes length 3 (5.5) 9 μm, width 1.5-2 μm, spines of 1-2 μm length. 20 specimens measured.
Comparison: The new species is in general smaller than the species described for the genus. *F. prismaticum* Rodriguez 1983 is also small, but it has the vesicle wall divided into polygonal fields. *F. pequenisimun* Rodriguez 1983 has smaller pinnae.

Florisphaeridium spp.

Genus ***Fractoricoronula*** Colbath emend. Turner 1984
Type species: *Fractoricoronula cubitalia* Colbath 1979
Fractoricoronula sp. Plate V, 17
Remarks: The single recorded specimen has the proximal part of the processes closed by the inner wall or plug, and a rounded end, which allow the positive assignment to *Fractoricoronula*

Genus ***Gorgonisphaeridium*** Staplin et al. emend. Kiryanov 1978
Type species: *Gorgonisphaeridium winslowiae* Staplin et al. 1965
Gorgonisphaeridium sp. A in Playford, 1977. Plate V, 18
Gorgonisphaeridium sp. B in Playford, 1977. Plate V, 19
Gorgonisphaeridium spp.

Genus ***Hoegklintia*** Dorning 1981
Type species: *Hogklintia visbyense (*Eisenack) Dorning 1981
Hoegklintia gogginensis Mullins 2001. Plate V, 20

Genus ***Inflatarium*** Le Hérissé et al. 2015
Type species: *Inflatarium trilobatum* Le Hérissé et al. 2015
Inflatarium trilobatum Le Hérissé et al. 2015. Plate V, 21
Inflatarium sp. Plate V, 22
Remarks: It is left in open nomenclature because the perpendicular lobe has not spines distally and seems to be open.

Genus ***Iroistella*** Deunff 1980
Type species: *Iroistella formidabilis* Deunff 1980
Iroistella formidabilis Deunff 1980. Plate V, 23
Iroistella sp. Plate V, 24
Remarks: The specimen has fewer processes than those described by Deunff (1980), although they have blunt bases and striation, allowing the assignment to the genus.

Genus ***Leiofusa*** Eisenack emend. Eisenack emend. Combaz et al. 1967

Type species: *Leiofusa fusiformis* Eisenack ex Eisenack, 1938
Leiofusa bernesgae Cramer 1964. Plate V, 25
Leiofusa filifera var. *filifera* Autonym 1975. Plate V, 26
Leiofusa spp.

Genus ***Lanveocia*** Deunff 1978
Type species: *Lanveocia formosa* Deunff 1978
cf. *Lanveocia* sp. Plate V, 27
Remarks: The specimen is badly preserved, hindering the assignment to the species described by Deunff (1978). The vesicle shape and longitudinal crests of processes are typical of the genus.

Genus ***Leprotolypa*** Colbath 1979
Type species: *Leprotolypa evexa* Colbath 1979, by original designation.
Leprotolypa gordonense (Cramer) Colbath 1979. Plate V, 28

Genus ***Lophodiacrodium*** Timofeev emend. Deflandre and Deflandre-Rigaud 1962
Type species: *Lophodiacrodium obversum* (Timofeev) Downie and Sarjeant 1965
Lophodiacrodium pepino (Cramer) Umnova 1975. Plate V, 29

Genus ***Lophosphaeridium*** Timofeev ex Downie emend. Lister 1970
Type species: *Lophosphaeridium rarum* Timofeev ex Downie, 1963, by original designation.
Lophosphaeridium spp.

Genus ***Micrhystridium*** Deflandre 1937
Type species: *Micrhystridium inconspicuum* Deflandre 1937
Micrhystridium adductum Wicander 1974. Plate V, 30
Micrhystridium complurispinosum Wicander 1974. Plate VI, 1
Micrhystridium erugatum Wicander 1974. Plate VI, 2
Micrhystridium simplex (Wicander) Eisenack et al. 1979. Plate VI, 3
Micrhystridium stellatum Deflandre 1945, Plate VI, 4
Micrhystridium sp. in García Muro et al., 2014. Plate VI, 5

Micrhystridium spp.

Genus ***Multiplicisphaeridium*** Staplin emend. Staplin et al. 1965
Type species: *Multiplicisphaeridium ramispinosum* Staplin, 1961
Multiplicisphaeridium arbusculiferum 1970. Plate VI, 6
Multiplicisphaeridium arbusculum Dorning 1981. Plate VI, 7
Multiplicisphaeridium asombrosum Cramer and Díez 1976. Plate VI, 8
Multiplicisphaeridium cladum (Downie) Eisenack 1969. Plate VI, 9
Multiplicisphaeridium fermosum Cramer 1970 ex Eisenack et al. 1973. Plate VI, 10
Multiplicisphaeridium fisheri (Cramer) Lister 1970. Plate VI, 11
Multiplicisphaeridium imitatum (Deflandre) Lister 1970. Plate VI, 12
Remarks: Sarjeant and Stancliffe (1994) classify the taxa as possible *Gorgonisphaeridium.* We do not agree with such taxonomic change, since the processes freely communicate with the vesicle interior.
Multiplicisphaeridium lindum Cramer and Díez 1976. Plate VI, 13
Multiplicisphaeridium mingusi Le Hérissé 1989. Plate VI, 14
Multiplicisphaeridium monki Le Hérissé 1989. Plate VI, 15
Multiplicisphaeridium paraguaferum (Cramer) Lister 1970. Plate VI, 16
Multiplicisphaeridium ramispinosum Staplin emend. Sarjeant and Vavrdová 1997. Plate VI, 17
Multiplicisphaeridium ramusculosum (Deflandre) Lister 1970. Plate VI, 18
Multiplicisphaeridium respa Cramer 1964. Plate VI, 19
Multiplicisphaeridium cf. *robertinum* (Cramer) Lister 1970. Plate VI, 20
Remarks: the recorded specimens are smaller (half size) than those described by Cramer (1964).
Multiplicisphaeridium rochesterense (Cramer and Díez) Eisenack et al. 1973. Plate VI, 21
Multiplicisphaeridium variabile (Lister) Dorning 1981. Plate VI, 22
Multiplicisphaeridium spp.

Genus ***Nanocyclopia*** Loeblich and Wicander 1976
Type species: *Nanocyclopia aspratilis* Loeblich and Wicander 1976
Nanocyclopia spp. Plate VI, 23-25

Remarks: Some specimens are similar to the *Nanocyclopia* sp. illustrated by Roesner et al. (2012), from the Lochkovian-Pragian of the Parnaíba Basin, Brazil.

Genus ***Navifusa*** Combaz et al. ex Eisenack 1976
Type species: *Navifusa navis* (Eisenack) Eisenack 1976
Navifusa spp. Plate VI, 26-27

Genus ***Neoveryhachium*** Cramer emend. Sarjeant and Stancliffe 1994
Type species: *Neoveryhachium carminae* (Cramer) Cramer 1970
Neoveryhachium carminae (Cramer) Cramer 1970. Plate VI, 28

Genus ***Onondagella*** Cramer emend. Playford 1977
Type species: *Onondagella asymmetrica* (Deunff ex Deunff) Cramer emend. Playford 1977
Onondagella asymmetrica (Deunff ex Deunff) Cramer emend. Playford 1977. Plate VI, 29

Genus ***Oppilatala*** Loeblich and Wicander 1976
Type species: *Oppilatala vulgaris* Loeblich and Wicander 1976
Oppilatala monterrosae (Cramer) Le Hérissé 1989. Plate VI, 30
Oppilatala cara (Cramer and Díez) Sarjeant and Vavrdová 1997. Plate VII, 1
Oppilatala grahni Le Hérisse 1989. Plate VII, 2
Oppilatala? *frondis* (Cramer and Díez) Dorning 1981. Plate VII, 3
Oppilatala cf. *ramusculosa ramusculosa* Le Hérissé 1989. Plate VII, 4
Remarks: The specimen of the Jaciara section is similar to the species described by Le Hérissé (1989), but smaller (22 μm vs. 13 μm).
Oppilatala spp.

Genus ***Ozotobrachion*** Loeblich and Drugg, 1968
Type species: *Ozotobrachion palidodigitatus* (Cramer) Playford 1977
Ozotobrachion palidodigitatus (Cramer emend. Cramer) Playford 1977. Plate VII, 5
Ozotobrachion pulvinus Loeblich and Wicander 1976. Plate VII, 6
Ozotobrachion spp.

Genua ***Passalosphaera*** Playford and Wicander 1988

Type species: *Passalosphaera minuta* Playford and Wicander 1988

Passalosphaera minuta Playford and Wicander 1988. Plate VII, 7-8

Remarks: According to the original description of the species, the vesicle diameter is 7-15 µm, but according to Vecoli et al. (2015) it can reach 25-33 µm. The diameter of the Jaciara specimen is 24 µm. It is the first record in strata younger than Ordovician, consequently it could be reworked.

Genus ***Perforela*** Cramer and Díez 1976

Type species: *Perforela perforata* Cramer and Díez 1976

Perforela perforata Cramer and Díez 1976. Plate VII, 9

Genus ***Polygonium*** Vavrdová 1966

Type species: *Polygonium gracilis* Vavrdová 1966

Polygonium polygonale (Eisenack ex Eisenack) emend. Le Hérissé 1989. Plate VII, 10

Polygonium spp.

Genus ***Pseudolunulidia*** Brito and Santos emend. Martin 1983

Type species: *Pseudolunulidia imperatrizensis* Brito and Santos 1965

Pseudolunulidia sp. Plate VII, 11

Genus ***Pulvinosphaeridium*** Eisenack restrict. Deunff emend. Sarjeant and Stancliffe 1994 (rejected by Mullins 2001)

Type species: *Pulvinosphaeridium pulvinellum* Eisenack 1954, by original designation.

Pulvinosphaeridium sp. Plate VII, 12-14

Remarks: The specimens recorded from the Jaciara section present an opening in the distal part of one of the processes, that could correspond to an excystment opening.

Comparison: They are smaller than *Pulvinosphaeridium trifidum* Kiryanov (1978), 224 µm vs. 47 µm in total length, and *P. trifidum* has straighter sides. Some specimens could be similar to those described by Quadros (1999) as *Trilobus expansus*, but specimens from Jaciara are smaller and the processes are broader. Only a few specimens were recorded and illustrated by Quadros (1999), making difficult the assignment to *Trilobus*.

Genus ***Pyloferites*** Quadros emend. García Muro et al. 2022

Type species: *Pyloferites pentagonalis* Quadros 1999, by original designation.

Pyloferites escobaides (Cramer) Daners et al. emend. García Muro et al. 2022. Plate VII, 15

Pyloferites paranaensis García Muro et al. 2022. Plate VII, 16.

Genus ***Riculasphaera*** Loeblich and Drugg 1968

Type species: *Riculasphaera fissa* Loeblich and Drugg 1968

Riculasphaera fissa Loeblich and Drugg 1968. Plate VII, 17

Remarks: The only specimen of *Riculasphaera loeblichii* Cramer and Díez (1976) illustrated by the authors could be a poorly preserved *R. fissa*.

Genus ***Schismatosphaeridium*** Staplin et al. 1965

Type species: *Schismatosphaeridium perforatum* Staplin et al. 1965

cf. *Schismatosphaeridium algerense* Cramer and Díez 1976. Plate VII, 18

Schismatosphaeridium guttulaferum Le Hérissé 1989. Plate VII, 19

Schismatosphaeridium perforatum Staplin et al. 1965. Plate VII, 20

Schismatosphaeridium sp. B in Le Hérissé, 1989. Plate VII, 21

Schismatosphaeridium spp.

Genus ***Thysanoprobolus*** Loeblich and Tappan 1970

Type species: *Thysanoprobolus polykion* Loeblich and Tappan 1970

cf. *Thysanoprobolus polykion* Loeblich and Tappan 1970. Plate VII, 22

Genus ***Tunisphaeridium*** Deunff and Evitt 1968

Type species: *Tunisphaeridium concentricum* Deunff and Evitt 1968

Tunisphaeridium caudatum Deunff and Evitt 1968. Plate VII, 23

Tunisphaeridium tentaculipherum (Martin) Cramer 1971. Plate VII, 24

Genus ***Tyligmasoma*** Playford 1977

Type species: *Tyligmasoma alargadum* (Cramer) Playford 1977

Tyligmasoma alargada (Cramer) Playford 1977. Plate VII, 25

Genus ***Uncinisphaera*** Wicander 1974

Type species: *Uncinisphaera lappa* Wicander 1974

Uncinisphaera acantha Wicander and Wood 1981. Plate VII, 26

Uncinisphaera cf. *ceratioides* (Stockmans and Willière) Colbath, 1990. Plate VII, 27

Remarks: The specimens recorded in Jaciara section are very variable (vesicle 13-21 µm, process number 2-16, processes length 3-13 µm).

Uncinisphaera tribulosa Wicander 1986. Plate VII, 28

Uncinisphaera spp.

Genus ***Veryhachium*** Deunff ex Downie 1959

Type species: *Veryhachium trisulcum* (Deunff) Deunff 1959

Veryhachium lairdii Group Deflandre ex Loeblich 1970. Plate VII, 29

Veryhachium trispinflatum Cramer 1964. Plate VII, 30

Veryhachium trispinosum (Eisenack) Stockmans and Willière 1962 Group. Plate VIII, 1

Genus ***Villosacapsula*** Loeblich and Tappan 1976

Type species: *Villosacapsula setosapellicula* (Loeblich) Loeblich and Tappan 1976

Villosacapsula helenae (Cramer) Loeblich and Tappan 1976. Plate VIII, 2

Villosacapsula irroratum (Loeblich and Tappan) Fensome et al. 1990. Plate VIII, 3

Villosacapsula leonensis (Cramer) Loeblich and Tappan 1976. Plate VIII, 4

Villosacapsula rosendae (Cramer ex Cramer) Loeblich and Tappan 1976. Plate VIII, 5

Villosacapsula sp. Plate VIII, 6

Remarks: Specimen similar to *Villosacapsula leonensis*, but bigger in size (60 vs. 80 µm).

Genus ***Visbysphaera*** Lister emend. Kiryanov emend. Le Hérissé 1989

Type species: *Baltisphaeridium dilatispinosum* Downie 1963, by original designation

Visbysphaera juliae (Cramer) Sarjeant and Vavrdová 1997. Plate VIII, 7

Visbysphaera sp. Plate VIII, 8

Genus ***Winwaloeusia*** Deunff 1977

Type species: *Winwaloeusia distracta* (Deunff) Deunff 1977

Winwaloeusia distracta (Deunff) Deunff 1977. Plate VIII, 9

Gen. et sp. indet. Plate VIII, 10-16

Description: Vesicle globose to polygonal in shape, with striate wall. Opening by simple split of the vesicle in half, with 5-10 short processes (1.5-5 μm length) per half. Processes are hollow and open to the vesicle interior, distally caulifoliar, or with 3-4 first-order subdivisions, starting close to the base. It is usual to found only the halves.
Dimensions: Vesicle 22 (31) 41 μm. 7 specimens measured.
Studied material: 5-61662 (X443), 5-61662 (O47), 6-61664 (J48/2), 12-61843 (D37/2), 16-61684 (E36), 16-61684 (Q37/4), 25-61702 (O32/1).
Comparison: These forms are close to *Schizocystia*, but the species included in this genus have fewer processes, up to 4, and mostly have a square vesicle shape. They are similar to *Pyloferites paranaensis* in general shape, number and type of processes, and ornamentation of the vesicle wall, but excystment of the genus *Pyloferites* is by means of a pylome.

Non-marine palynomorphs
Coenobial
Genus ***Deflandrastrum*** Combaz 1962
cf. *Deflandrastrum* sp. Plate VIII, 17-19
Remarks: Although the Jaciara specimens are few and badly preserved, it is possible to distinguish the structure of triangular cells in the same plane, delineating a central subcircular shape.

Genus ***Quadrisporites*** Hennelly ex Potonié and Lele 1961
Type species: *Quadrisporites horridus* Hennelly 1959
Quadrisporites horridus (Hennelly) ex Potonié and Lele 1961. Plate VIII, 20
Quadrisporites granulatus (Cramer) Strother 1991. Plate VIII, 21
Quadrisporites sp. in Oliveira and Burjack, 1996. Plate VIII, 22
Quadrisporites spp.

Zytgnemataceae
Genus ***Peltacystia*** Balme and Segroves, 1966
Type species: *Peltacystia venosa* Balme and Segroves 1966
Peltacystia sp. Plate VIII, 23-25
Studied material: 23-61854 (N38/3), 22-61696 (G46), 22-61696 (J35/4), 1-61654 (L35/3), 1-61654 (P44/1), 1-61832 (F29/3), 2-61655 (H47), 2-61833 (Q34/4), 2-61655

(V39/2), 2-61655 (P41/4), 5-61662 (X44), 7-61666 (R26/1), 9-61670 (P43/1), 10-61671 (N52/1), 12-61843 (C50/3), 13-61678 (L35/4), 15-61682 (P32/2).

Description: Isolated saucer- or canoe-shaped halves. Most of specimens of the Jaciara section present a subtle gradation from the ornamented equatorial zone to the polar zone. The equatorial zone bears radially disposed ribs of 3-6 μm in width, separated by grooves of 1 μm. The ribs taper from the line of the equatorial rupture to the circumpolar part. The polar zone is levigate to rugulate.

Dimensions: 44 (72) 83 μm. 13 specimens measured.

Previous records: The earliest *Peltacystia* record known so far is from the upper Permian (Balme and Segroves, 1965; Mays et al., 2021). Therefore, its presence in the Jaciara section constitutes the oldest occurrence of the genus.

Fresh water Chlorococales

Genus ***Musivum*** Wood and Turnau 2001

Type species: *Musivum gradzinskii* Wood and Turnau 2001

Musivum gradzinskii Wood and Turnau 2001. Plate VIII, 26

Fresh water Acritarchs

Genus ***Schizocystia*** Cookson and Eisenack emend. Jardiné et al. 1972

Remarks: According to the original descriptions of *S. pilosa* (Jardine et al., 1972) and *S. saharica*, they have scabrate to microverrucose wall (Jardine et al., 1974). Some specimens from the Jaciara section present prominent verrucose wall ornamentation. The verrucae are irregularly distributed (e.g., Plate VIII, 27), similar to those of the Amazon Basin (Steemans et al., 2008), which were classified as *Schizocystia* sp. The irregular distribution and variable dimension of the ornamentation are probably related to intraspecific variability. In addition, some specimens have more than one process per corner (e.g., Plate VIII, 27-28,). Despite the differences observed, the characteristics still match the genus and species diagnosis. Therefore, the Jaciara specimens are positively assigned to *S. pilosa* or *S. saharica*.

Schizocistia pilosa Jardiné et al. 1972. Plate VIII, 27-30.

Remarks: Some specimens from the Lochkovian of the Amazon Basin, assigned to *Pulvinosphaeridium brasiliensis nom. nud.* by Roesner et al. (2012, p. 138, fig. 2.4-5), could actually be assigned to *S. pilosa* (Plate VIII, 30).

Schizocystia saharica Jardiné et al. 1974 Plate IX, 1-4

Remarks: *Schizocystia saharica* variant 1, from the Lochkovian of the Solimões Basin (Rubinstein et al., 2008) has very variable processes, in length and width, bifurcate or trifurcate, with branched or roughly digitated or ramified distal ends (p. 178, fig. 7.13-15). Taking into account the intraspecific variability of *S. saharica*, specimens previously assigned to variant 1 are considered here as *S. saharica s.l.*.

Genus ***Botryococcus*** Kützing 1849
Type species: *Botryococcus braunii* Kützing 1849
Botryocuccus spp. Plate IX, 5

Another organic component
Cuticles and phytoclasts were the only components counted for palynofacies analyses, since the relative abundance of the rest was markedly minor. Anyway, they were illustrated to show the diversity of the recognized organic components.
Cuticles. Plate IX, 6-9
Clusters indet. Plate IX, 10-11
Phytoclasts. Plate IX, 12-14
Tubes. Plate IX, 15-16
Scolecodonts. Plate IX, 17-18.
Zooclasts. Plate IX, 19-20.

3.1.Biostratigraphy
García Muro et al. (2020) published the miospores analysis of the assemblage recorded in the Jaciara section, Paraná Basin. The main references to date the unit were the miospore biozonation established by Melo and Loboziak (2003) for the Amazon Basin, and the biozones of Breuer and Steemans (2013) for northwestern Gondwana (North Africa and Saudi Arabia). The miospore assemblages allowed the identification of a Late Pragian to possibly middle Emsian age for the studied section.
As for the phytoplankton, younger and older species than the age suggested by the miospores, were recovered. Phytoplankton key species that first appear in the Pragian are present since the lowermost samples (Fig. 8), such as *Bimerga paula*, *B. nuda*, *B. acharii*, *Exochoderma triangulata*, *Palacanthus ledanoisii*, *Pyloferites escobaides* (e.g., Daners et al., 2017; Rubinstein et al., 2017; García Muro et al., 2021).

Noticeable, all species of the *Bimerga* genus are present in the section, and are common in the lowermost samples. *Bimerga* is a biostratigraphical and palaeobiogeographical useful genus, because it is restricted to the Devonian of Gondwana. According to Daners et al. (2017) the species *B. bensonii* should be younger in age, but it appears in the Pragian samples, up to sample 2, together with other species of the genus. *B. bensonii* was firstly recorded from the Middle Devonian of Los Monos Formation, in Bolivia (Wood, 1995). Therefore, the finding of *B. bensonii* in the Ponta Grossa Formation, reveals an older first appearance in the Early Devonian. Noetinger and di Pasquo (2013) indicated the presence of *B. bensonii* in the PET2 Association, dated as early Pragian, but the illustrated specimen (fig. 4B) would correspond to *B. paula*, which is considered older in age. Similarly, Mendlowicz-Mauller et al. (2007) illustrated a specimen of *B. bensonii* (fig. 6, 2), from the same section studied here, dated as Emsian, but the specimen is not well preserved. Gaugris and Grahn (2006) also mentioned the presence of *B. bensonii* in the Ponta Grossa Formation, in Late Pragian-Emsian strata, but the specimen is not illustrated. Thus, the presence of *B. bensonii* in the Jaciara section represents the oldest confirmed record for this species, corresponding to the late Pragian.

The sample 4 yields *Navifusa* sp. Even though *Navifusa* is known from Ordovician strata, it has not been recorded from the Silurian to the Pragian, reappearing in the Emsian (Molyneux et al., 1996; Rietka and Brocke, 2008; Bosetti et al., 2012; Grahn et al., 2013; García Muro et al., 2017). Therefore, its presence suggests an Emsian age from this sample, at almost 2.5 m from the base onwards. Based on the miospore assemblage, an Emsian age was confirmed for the next sample (5), at 24 m from the base (García Muro et al., 2020), due to the presence of *Cymbosporites asymmetricus*. This trilete spore species is the index species of the *asymmetricus* Subzone of the *ovalis-biornatus* Biozone of northwestern Gondwana (Breuer and Steemans, 2013). Additionally, some spores, such as *Brochotriletes bellatulus* and *Verrucosisporites* sp. 1, of samples 2- 4 also suggest an Emsian age, based on both, phytoplankton and miospores, the Emsian age is now confirmed from sample 4.

Mendlowicz Mauller et al. (2007) indicated the presence of *Anthatractus insolitus* in the Jaciara section, in sample 17, at 24 m deep, which would confirm the Emsian age for this part of the section. Although, these authors illustrated a specimen, they did not include further information of its localization in the section. *Anthatractus insolitus* was not found in the present study, even though the samples come from the same levels of

Mendlowicz Mauller et al. (2007). Nevertheless, in accordance with these authors, this part of the section would not be older than early Emsian, supported by the occurrence of the phytoplankton species *Navifusa* sp. and *Pterospermella pernambucensis* (Molyneux et al., 1996; Fatka and Brocke, 2008; García Muro et al., 2018).

The middle to upper part of the section yields phytoplankton species such as *Pterospermella reticulata*, *Polyedryxium pharaone*, *Costatilobus undulatus* that match with an Emsian age (e.g., Playford, 1977; Ravn and Benson, 1988; Wicander and Wood, 1997; di Pasquo et al., 2009).

The upper part of the section was dated as possible middle Emsian by García Muro et al. (2020). This younger age, based on the presence of *Granulatisporites concavus* in sample 25, had never been registered until that time for the Ponta Grossa Formation. This species first occurs in the *lindlarensis-sextantii* Biozone (Breuer and Steemans, 2013), which corresponds to the middle to late Emsian. Although the key species of this biozone are absent, a younger age could be suggested. Among the phytoplankton, there are no species that can confirm the middle Emsian age given by the miospores. The palynomorphs tend to be scarcer and badly preserved towards the upper part of the section, accompanied by an increase of phytoclasts, suggesting a shallowing trend upwards in the succession.

Species such *Cymatiosphaera acinosa* Wicander 1974 and *Pterospermella timofeevi* Deunff 1966, previously known from the Middle and Late Devonian, present their lowest records in the late Pragian and late- early Emsian of the Jaciara section, respectively. Conversely, *Costatilobus aremoricanus* Deunff 1980 and *Uncinisphaera tribulosa* Wicander 1986, both of Lochkovian age, present in Jaciara their youngest records, in the late Pragian and Emsian respectively. A possible specimen of *Tysanoprobolus polykion* was also recorded. Such species was classically considered to range up to the Lochkovian (Wicander and Playford, 2021 and references therein), nonetheless, it was lately recognized in the possible Late Pragian in the Argentinean Precordillera (Gracía Muro et al., 2017).

Additionally, some species not found so far from strata younger than Silurian are present in the studied section. It is the case of species such as *Ammonidium microcladum* Lister 1970 (e.g., Le Hérrissé et al., 1995; Molyneux et al., 2008), *Arkonia nova* and *A. paulumstriata* (Le Hérissé, 2002), *Cymatiosphaera mariae* (Cramer et al., 1976; Stricanne et al., 2006; Rubinstein and García Muro, 2011), *Dateriocradus tribrachiata* Dorning, 1981. Ordovician species such as *Inflatarium trilobatum* Le

Hérissé et al., 2015 and *Dicommopalla* sp. (Loeblich, 1970; Delabroye et al., 2011), are also present in the Early Devonian of the Jaciara section. These oldest taxa are well preserved and of the same color as other palynomorphs. They appear more frequently in the section since sample 1-2, that is at the lower part of PSIII, at the beginning of a flooding event. The appearance of species with records no younger than Ordovician or Silurian, in addition to the fact that many of them have very few records worldwide, could be interpreted either as reworking or as an extension of their stratigraphic ranges.

4. Conclusions

The phytoplankton assemblage here presented is the most diverse published so far for the Ponta Grossa Formation and for the Devonian of Brazil with almost 200 species recognized.

The remarkable preservation of the palynomorphs in most of the samples and the detailed analysis of the assemblage, allowed the validation of species that were previously informally described or mentioned. Some taxa present in the section extend their worldwide stratigraphic ranges, adding new valuable information mainly to the Devonian palynology of South America and Gondwana.

Correlation with miospore assemblages from the same section allows confirmation of the late Pragian age for the lower part of the section and a more accurate position of the Pragian- Emsian boundary. However, the middle Emsian age could not be corroborated.

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Captions

Figure 1. Geographical map of the Jaciara section. Modified from García Muro and Rubinstein (2022).

Figure 2. Lithostratigraphic scheme of the Lower-Middle Devonian Paraná Basin (modified from Grahn et al., 2013). Ti.: Tibagi Member of the São Domingos Formation; C.G. u3: Chapada Group unit 3.

Figure 3. Sedimentological section with locations of the studied samples, the TOC and 13Corg data (see García Muro et al., 2020) and the relative abundance of organic matter components.

Figure 4. Stratigraphic distribution of the Chlorophytes in the Jaciara section. Black squares indicate positively identified species; grey squares indicate cf. species and light grey squares indicate supposed stratigraphic range.

Figure 5. Stratigraphic distribution of the acritarchs in the Jaciara section. Black squares indicate positively identified species; grey squares indicate cf. species and light grey squares indicate supposed stratigraphic range.

Figure 6. Stratigraphic distribution of the acritarchs in the Jaciara section. Black squares indicate positively identified species; grey squares indicate cf. species and light grey squares indicate supposed stratigraphic range.

Figure 7. Stratigraphic distribution of the non-marine palynomorphs in the Jaciara section. Black squares indicate positively identified species; grey squares indicate cf. species and light grey squares indicate supposed stratigraphic range.

Figure 8. Global stratigraphic distribution of selected phytoplankton species. The grey/pink bar indicates the suggested age of the studied section.

Plate I. 1, *Cymatiosphaera acinosa*, sample 24-61700 (S36); **2,** *Cymatiosphaera daioariochora*, sample 24-61700 (Y43/2); **3,** *Cymatiosphaera* cf. *jardinei*, sample 23-61698 (E49/4); **4,** *Cymatiosphaera lawsonii*, sample 22-61696 (N44); **5,** *Cymatiosphaera* aff. *ledburica*, sample 22-61696 (J40/3); **6,** *Cymatiosphaera mariae*, sample 1-61654 (S33/2); **7,** *Cymatiosphaera mirabilis*, sample 23-61698 (V29/4); **8,** *Cymatiosphaera multisepta*, sample 22-61696 (H29); **9,** *Cymatiosphaera nebulosa*, sample 1-61654 (M29/1); **10,** *Cymatiosphaera* cf. *nimia*, sample 23-61698 (E29); **11,** *Cymatiosphaera octoplana*, sample 23-61698 (L46/1); **12,** *Cymatiosphaera paucimembranae*, sample 11-61674 (X36); **13,** *Cymatiosphaera peligrosa*, sample 27-61706 (P28/4); **14,** *Cymatiosphaera perimembrana*, sample 24-61700 (T37/3); **15,** *Cymatiosphaera prismática*, sample 23-61698 (H43/1); **16,** *Cymatiosphaera*

rhacoamba, sample 20-61692 (N38/3); **17,** *Cymatiosphaera tryphera*, sample 23-61698 (T4671); **18,** *Cymatiosphaera velicarina*, sample 24-61700 (U28/1); **19,** *Cymatiosphaera winderi*, sample 24-61700 (E42/4); **20,** *Cymatiosphaera* sp. in Rubinstein et al., 2017, sample 24-61700 (Q48); **21,** *Cymatiosphaera* sp.1, sample 24-61700 (T50); **22,** *Dictyotidium variatum*, sample 23-61698 (K49/1); **23,** *Dictyotidium* sp., sample 10-61841 (F33/4); **24,** *Melikeriopalla fissura*, 24-61700 (H35/3); **25,** *Pterospermella brasiliensis*, sample 18-61688 (N43/2); **26,** *Pterospermella circumstriata*, sample 2-61655 (J44/3); **27-30,** *Pterospermella crassimarginata*, samples 15-61682 (D39/2), 19-61690 (U34), 11-61674 (K23), 12-61843 (D45/2). Scale bar: 20 μm.

Plate II. 1, *Pterospermella elliptica*, sample 15-61682 (U29/4) **2,** *Pterospermella guapita*, sample 61704 (U29); **3,** *Pterospermella* cf. *latibaltheus*, sample 24-61700 (N24/4); **4,** *Pterospermella martinii*, sample 22-61696 (N32/4); **5,** *Pterospermella pernambucensis*, sample 6-61664 (Z43); **6,** *Pterospermella* cf. *radiata*, sample 24-61700 (U37/2); **7,** *Pterospermella* cf. *rajada*, sample 21-61694 (W40/3); **8,** *Pterospermella reticulata*, sample 15-61682 (O25); **9,** *Pterospermella timofeevi*, 21-61694 (U37/1); **10-12,** *Pterospermella tiaraiarense*, samples 4-61660 (R46/4); 8-61668 (J35); 21-61694 (Q46/4); **13,** Tasmanites sp, 23-61698 (F29/2); **14,** *Baculatireticulatus* sp., sample 23-61698 (V41/4); **15,** *Duvernaysphaera angelae*, sample 25-61702 (T41/1); **16,** cf. *Duvernaysphaera stellata*, sample 25-61702 (T40/2); **17,** cf. *Duvernaysphaera wilsonii*, sample 26-61704 (P42/4); **18,** *Hemiruptia* sp., sample 18-61688 (R21/4); **19,** *Muraticavea munificus*, sample 8-61668 (Q23); **20,** *Palacanthus ledanoisii*, sample 12-61843 (T42/3); **21,** *Palacanthus* cf. *ledanoisii*, sample 11-61674 (V38/3); **22,** *Polyedryxium*? *asperum*, sample 23-61698 (U25/3); **23,** *Polyedryxium calculosum*, sample 22-61696 (N44/3); **24,** *Polyedryxium carnatum*, sample 24-61700 (W38/1); **25,** *Polyedryxium condensum*, sample 4-61835 (T43/1); **26,** *Polyedryxium decorum*, sample 15-61682 (V36/1); **27,** *Polyedryxium*? *embudum*, sample 23-61698 (Y26/2); **28,** cf. *Polyedryxium evolutum*, sample 14-61680 (O43); **29,** *Polyedryxium fragosulum*, sample 4-61660 (N49/2); **30,** *Polyedryxium helenaster*, sample 15-61682 (F50). Scale bar: 20 μm.

Plate III. 1, *Polyedryxium multifrons*, sample 14-61680 (P45); **2,** *Polyedryxium nudatum*, sample 24-61700 (Q24); **3,** *Polyedryxium pharaone*, sample 6-61664 (S40/4); **4,** *Polyedryxium simplex*, sample 7-61666 (L34/2); **5,** *Polyedryxium* cf. *talus*, sample 4-

61660 (H31/1); **6,** *Polyplanifer turbatum*, sample 9-61840 (M27/4); **7,** *Stellinium micropolygonale*, sample 8-61668 (E28/3); **8,** *Stellinium rabians*, sample 14-61680 (G45); **9,** *Stellinium*? *tetrahedroide*, sample 3-61658 (K27/3); **10,** *Acriora petala*, sample 24-61700 (S48); **11,** *Ammonidium inornatum*, sample 1-61654 (V44); **12,** *Ammonidium maravillosum*, sample 10-61671 (S37); **13,** *Ammonidium microcladum*, sample 4-61660 (E43/1); **14,** *Ammonidium uncinum*, sample 14-61680 (F33/4); **15,** *Ammonidium waldronense*, sample 11-61674 (V37/2); **16,** *Arkonia nova*, sample 19-61690 (J40); **17-18,** *Arkonia paulumstriata*, samples 11-61674 (H46); 21-61694 (S41/1); **19,** *Bimerga acharii*, sample 23-61854 (G51/4); **20-21,** *Bimerga bensonii*, samples 23-61698 (J34/4); 23-61698 (D30); **22,** *Bimerga nuda*, sample 6-61664 (Q39/4); **23,** *Bimerga paula*, sample 23-61854 (O26). Scale bar: 20 μm.

Plate IV. 1, cf. *Bimerga* sp., sample 25-61702 (D41/4); **2,** *Buedingiisphaeridium* cf. *pyramidale*, sample 23-61698 (J38); **3,** *Cordobesia oriental*, sample 22-61696 (Q35); **4,** *Cordobesia uruguayensis*, sample 22-61696 (Q32); **5,** *Costatilobus aremoricanus*, sample 11-61674 (H38/1); **6,** *Costatilobus undulatus*, sample 7-61666 (M48/2); **7,** *Costatilobus* sp., sample 3-61658 (X44/4); **8,** *Crassiangulina tesselita*, sample 5-61662 (J44/2); **9,** *Cymbosphaeridium* sp., sample 2-61655 (K50); **10,** *Dateriocradus tribrachiata*, sample 10-61671 (K46/1); **11,** *Dateriocradus* sp. B in Playford 1977, sample 24-61700 (Q24); **12,** *Dateriocradus* sp., sample 8-61668 (T36/2); **13-16,** *Diaphorochroa gracile* sp. nov., samples 1-61654 (K40/1); 2-61655 (P36/4); 5-61662 (Q44/3); 16-61684 (M24/3); **17,** *Diexallophasis remota* Group, sample 3-61658 (M46/1); **18,** *Diexallophasis simplex*, sample 22-61696 (O46/2); **19,** *Dicommopalla* sp., sample 22-61834 (M30/2); **20,** *Dorsennidium cantabricum*, sample 21-61694 (T40/3); **21,** *Dorsennidium estrellitae*, sample 11-61674 (G46/1); **22,** *Dorsennidium europaeum*, sample 13-61678 (N25); **23,** *Dorsennidium polyaster*, sample 22-61690 (M46/3); **24,** *Ecmelostoiba* cf. *asymmetrica*, sample 19-61678 (G37/2); **25,** *Estiastra barbata*, sample 22-61696 (U37/3); **26,** *Estiastra culcita*, sample 10-61671 (E45); **27,** *Estiastra stellata*, sample 25-61702 (Y41); **28,** *Estiastra uruguaia*, sample 16-61684 (S24); **29,** *Estiastra* sp. in Ottone 1996, sample 17-61686 (V48/3); **30,** *Eupoikilofusa stratifera*, sample 21-61694 (J42/1). Scale bar: 20 μm.

Plate V. 1, *Evittia geometrica*, sample 1-61654 (U25); **2,** *Evittia sanpetrensis*, sample 4-61660 (E41/3); **3,** *Evittia sommeri-Evittia geométrica* Group, sample 16-61684 (J47/4); **4,** *Evittia sommeri*, sample 22-61696 (O29); **5,** *Exochoderma arca*, sample 15-

61682 (V43); **6,** *Exochoderma arca* Wicander and Wood 1981-*Evittia sommeri* Brito 1967 transient forms, sample 24-61700 (N31); **7,** *Exochoderma irregulare*, sample 19-61690 (V37/3); **8-9,** *Exochoderma triangulata*, samples 1-61654 (U25), 18-61668 (V41/2); **10,** *Filisphaeridium muscosum*, sample 24-61700 (K48/3); **11,** *Florisphaeridium pequenisimum*, sample 24-61700 (U49/2); **12,** *Florisphaeridium toyetae*, sample 23-61698 (F49/4); **13-16,** *Florisphaeridium brasiliensis*, samples 11-61674 (R23/4), 14-61845 (W42/2), 22-61696 (M24/3), 21-61694 (G33/1); **17,** *Fractoricoronula* sp., sample 6-61664 (Q40); **18,** *Gorgonisphaeridium* sp. A in Playford 1977, sample 2-61655 (L41/2); **19,** *Gorgonisphaeridium* sp. B in Playford 1977, sample 23-61700 (T36); **20,** *Hoegklintia gogginensis*, sample 24-61700 (S36/4); **21,** *Inflatarium trilobatum*, sample 12-61676 (N44); **22,** *Inflatarium* sp., sample 12-61676 (V42/3); **23,** *Iroistella formidabilis*, sample 61700 (L29/3); **24,** *Iroistella* sp., sample 11-61674 (V37/3); **25,** *Leiofusa bernesgae*, sample 6-61664 (G38/1); **26,** *Leiofusa filifera* var. *filifera*, sample 23-61698 (U43/3); **27,** cf. *Lanveocia* sp., sample 15-61682 (V40/3); **28,** *Leprotolypa gordonense*, sample 25-61702 (P49/4); **29,** *Lophodiacrodium pepino*, sample 7-61666 (D42/3); **30,** *Micrhystridium adductum*, sample 9-61670 (E49). Scale bar: 20 µm.

Plate VI. 1, *Micrhystridium compl.rispinosum*, sample 23-61854 (F48); **2,** *Micrhystridium erugatum*, sample 14-61845 (S43/1); **3,** *Micrhystridium simplex*, sample 8-61668 (G33/1); **4,** *Micrhystridium stellatum*, 7-61838 (D47); **5,** *Micrhystridium* sp. in García Muro et al. (2014), sample 7-61666 (O30/3); **6,** *Multiplicisphaeridium arbusculiferum*, sample 5-61636 (T33/1); **7,** *Multiplicisphaeridium arbusculum*, sample 21-61694 (G29); **8.** *Multiplicisphaeridium asombrosum*, sample 18-61688 (G47/2); **9,** *Multiplicisphaeridium bladum*, sample 13-61678 (K38/4); **10,** *Multiplicisphaeridium fermosum*, sample 11-61674 (S33/3); **11,** *Multiplicisphaeridium fisheri*, sample 21-61658 (U27/3); **12,** *Multiplicisphaeridium imitatum*, sample 11-61674 (O41/4); **13,** *Multiplicisphaeridium lindum*, sample 2-61655 (R51); **14,** *Multiplicisphaeridium mingusi*, sample 19-61690 (L47); **15,** *Multiplicisphaeridium monki*, sample 26-61704 (G44/3); **16,** *Multiplicisphaeridium paraguaferum*, sample 8-61668 (T47); **17,** *Multiplicisphaeridium ramispinosum*, sample 5-61662 (O49/3); **18,** *Multiplicisphaeridium ramusculosum*, sample 22-61696 (K37/3); **19,** *Multiplicisphaeridium raspa*, sample 9-61670 (Q26/1); **20,** *Multiplicisphaeridium* cf. *robertinum*, sample 5-61662 (S23); **21,** *Multiplicisphaeridium rochesterense*, sample 21-61694 (X42/4); **22,** *Multiplicisphaeridium variabile*, sample 9-61670 (V33/3); **23-**

25, *Nanocyclopia* spp., samples 24-61855 (F30), 22-61696 (U28/2); 5-61662 (R23/2); **26-27,** *Navifusa* spp., samples 4-61660 (P43/3), 9-61840 (T29/1); **28,** *Neoveryhachium carminae*, sample 22-61696 (H39/2); **29,** *Onondagella asymmetrica*, sample 22-61696 (M33); **30,** *Oppilatala monterrosae*, sample 8-61668 (V34/4). Scale bar: 20 μm.

Plate VII. 1, *Oppilatala cara*, sample 11-61674 (W36/2); **2,** *Oppilatala grahni*, sample 13-61678 (Q25/3); **3,** *Oppilatala*? *frondis*, sample 4-61660 (R48); **4,** *Oppilatala* cf. *ramusculosa ramusculosa*, sample 22-61696 (F40); **5,** *Ozotobrachion palidodigitatus*, sample 8-61668 (V44/2); **6,** *Ozotobrachion pulvinus*, sample 4-61660 (F31/1); **7-8,** *Passalosphaera minuta*, samples 22-61696 (H24/4); 2261696 (L43/2); **9,** *Perforela perforata*, 17-61686 (T48/3); **10,** *Polygonium polygonale*, 19-61690 (R48/3); **11,** *Pseudolunulidia* sp., sample 15-61682 (O48/2); **12-14,** *Pulvinosphaeridium* spp., samples 7-61666 (S27/1); 9-61670 (S46); 11-61674 (S45/2); **15,** *Pyloferites escobaides*, sample 11-61674 (J23); **16,** *Pyloferites paranaensis*, sample 21-61694 (S48/2); **17,** *Riculasphaera fissa*, sample 8-61668 (J35/1); **18,** cf. *Schismatosphaeridium algerense*, sample 20-61692 (R26); **19,** *Schismatosphaeridium guttulaferum*, sample 11-61674 (J46); **20,** *Schismatosphaeridium perforatum*, sample 11-61674 (S32); **21,** *Schismatosphaeridium* sp. B in Le Hérissé, 1989, sample 14-61680 (O23/1); **22,** cf. *Thysanoprobolus polykion*, sample 21-61694 (P23/4); **23,** *Tunisphaeridium caudatum*, sample 14-61680 (Y48/2); **24,** *Tunisphaeridium tentaculipherum*, sample 8-61668 ((R37/3); **25,** *Tyligmasoma alcrgeda*, sample 23-61698 (J29); **26,** *Uncinisphaera acantha*, sample 5-61662 (T47); **27,** *Uncinisphaera* cf. *ceratioides*, 19-61690 (K31/2); **28,** *Uncinisphaera tribulosa*, sample 8-61668 (W39); **29,** *Veryhachium lairdii* Group, sample 25-61702 (M41); **30,** *Veryhachium trispinflatum*, sample 21-61694 (G25). Scale bar: 20 μm.

Plate VIII. 1, *Veryhachium trispinosum*, sample 26-61704 (K35); **2,** *Villosacapsula helenae*, sample 12-61676 (G50); **3,** *Villosacapsula irroratum*, sample 16-61684 (O48/2); **4,** *Villosacapsula leonensis*, sample 8-61668 (T21/2); **5,** *Villosacapsula rosendae*, sample 3-61658 (S44/1); **6,** *Villosacapsula* sp., sample 15-61682 (O29); **7,** *Visbysphaera juliae*, sample 23-61698 (O32); **8,** *Visbysphaera* sp., sample 24-61700 (F49); **9,** *Winwaloeusia distracta*, sample 13-61844 (K29/4); **10-16,** Gen. et sp. indet., samples 5-61662 (X44/3), 5-61662 (O47), 6-61664 (J48/2), 12-61843 (D37/2), 16-61684 (E36), 16-61684 (Q37/4), 25-61702 (O32/1); **17-19,** cf. *Deflandrastrum* sp., samples 7-61838 (Q33/1), 13-61678 (N29/3), 21-61694 (J37/1); **20,** *Quadrisporites horridus*, sample 15-61682 (X36); **21,** *Quadrisporites granulatus*, sample 17-61686

(J32/3); **22,** *Quadrisporites* sp. in Oliveira and Burjack, 1996, sample 24-61855 (X31); **23-25,** *Peltacystia* sp., samples 23-61854 (N38/3), 1-61832 (F29/3), 9-61670 (P43/1); **26,** *Musivum gradzinskii*, sample 15-61846 (U49/3); **27-30,** *Schizocistia pilosa*, samples 1-61654 (H46/1), 1-61654 (H47/3), 25-61702 (V48/2), 9-61840 (F34/1). Scale bar: 20 μm.

Plate IX. 1-4, *Schizocystia saharica*, samples 8-61668 (U29/4), 8-61668 (W45), 9-61670 (Q47), 18-61688 (L28); **5,** *Botryocuccus* sp., sample 24-61700 (K44/1); **6-9,** cuticle, samples 15-61682 (J31/2), 15-61682 (O51/1), 15-61846 (R49), 16-61684 (T48/2); **10-11,** Cluster indet, samples 8-61839 (N26/3), 18-61688 (H35/2); **12-14,** Phytoclasts, sample 10-61671 (K44/3), 25-61702 (W42/3), 27-61694 (N32); **15-16,** Tubes, samples 11-61674 (Q39), 19-61690 (R33/1); **17-18**, Scolecodont, samples 25-61702 (Q40/4), 7-61838 (P51); **19-20,** Zooclast, samples 9-61670 (H23), 9-61670 (W23/2). Scale bar: 20 μm.

Declaration of Competing Interest

There is no confict of interest.

Highlights (3 to 5 bullet points, maximum 85 characters, including spaces, per bullet point)

- Diversity and preservation of the phytoplankton assemblage is remarkable
- New taxonomic, palaeobiogeographical and biostratigraphical information is provided
- The age given by the phytoplankton is correlated with the one given by the miospores

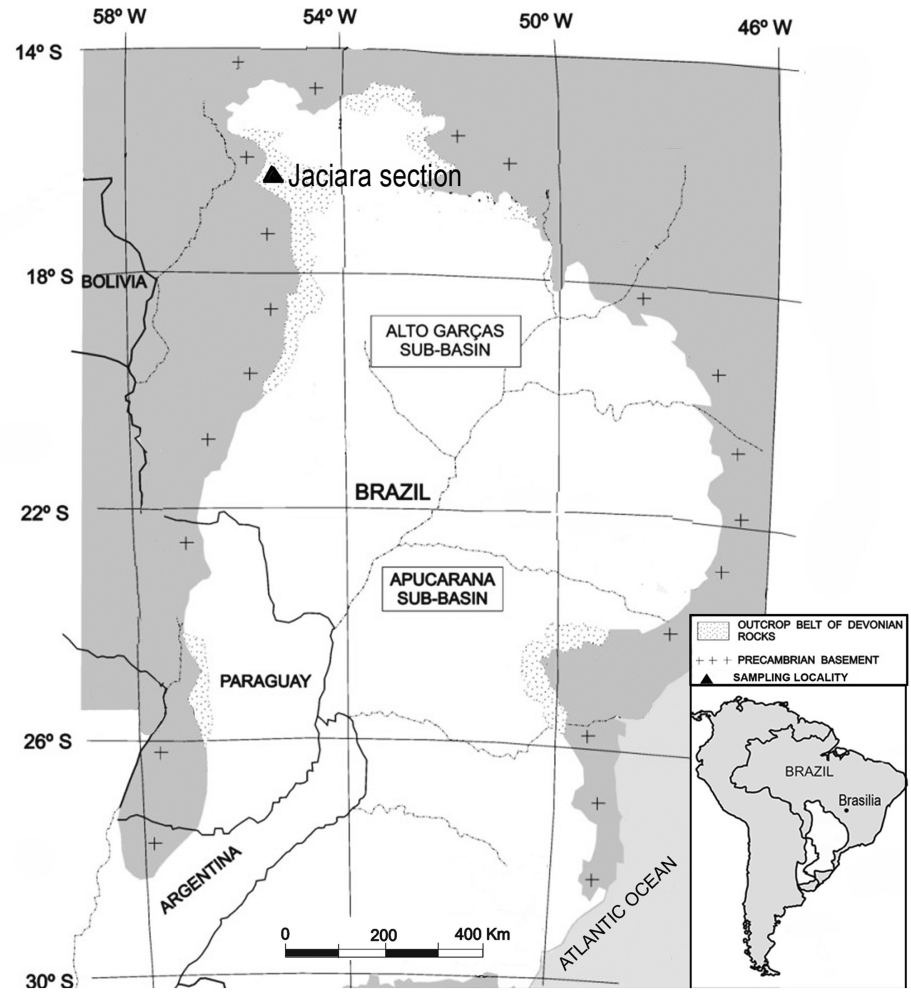
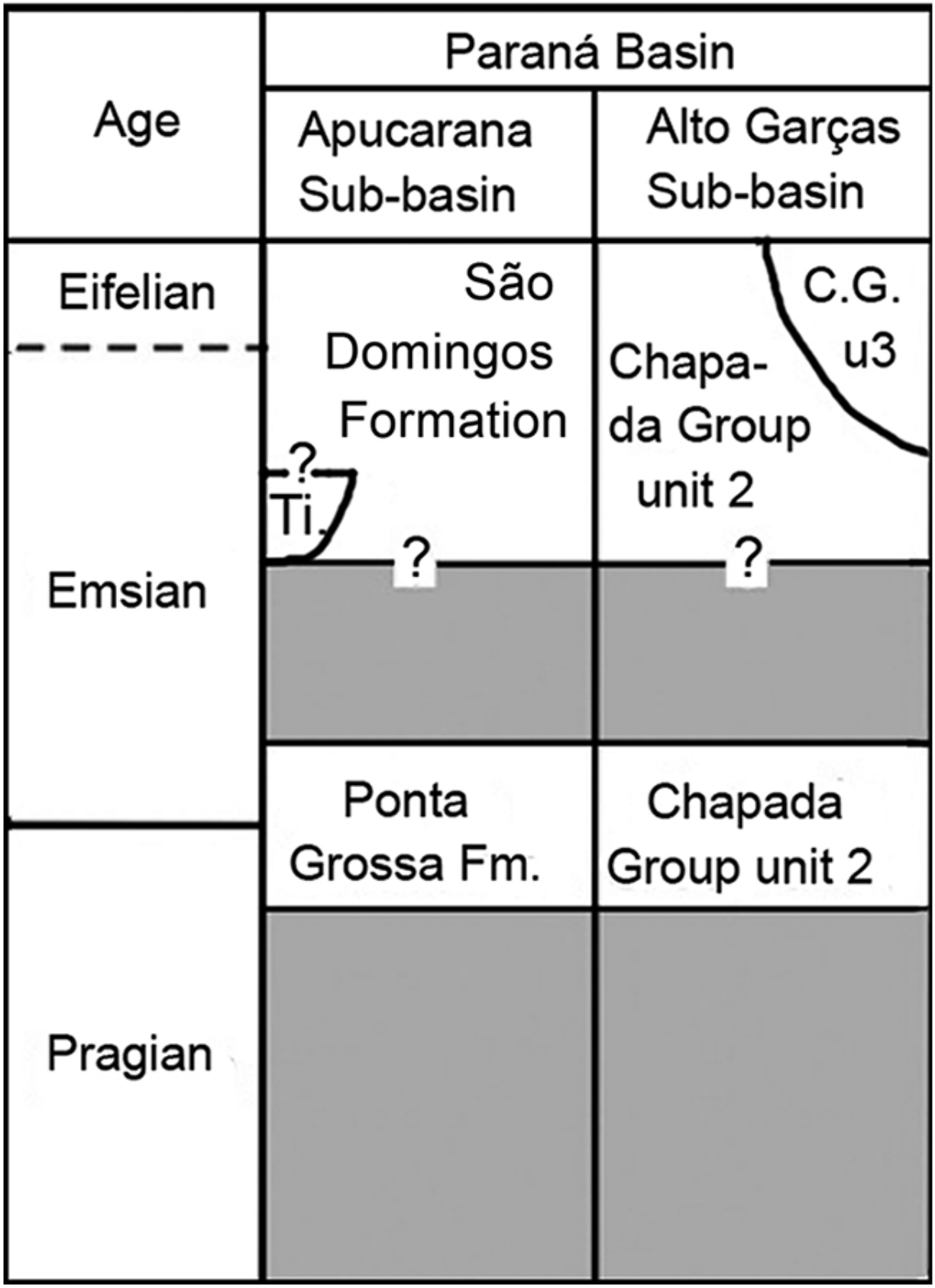

58° W
54° W
50° W
46° W
14° S
18° S
22° S
26° S
30° S
Jaciara section
BOLIVIA
ALTO GARÇAS SUB-BASIN
BRAZIL
APUCARANA SUB-BASIN
PARAGUAY
ARGENTINA
ATLANTIC OCEAN
0
200
400 Km
OUTCROP BELT OF DEVONIAN ROCKS
PRECAMBRIAN BASEMENT
SAMPLING LOCALITY
BRAZIL
Brasilia

Figure 1


Age
Paraná Basin
Apucarana Sub-basin
Alto Garças Sub-basin
Eifelian
São Domingos Formation
C.G. u3
Chapa-da Group unit 2
?
Ti
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Emsian
Ponta Grossa Fm.
Chapada Group unit 2
Pragian

Figure 2

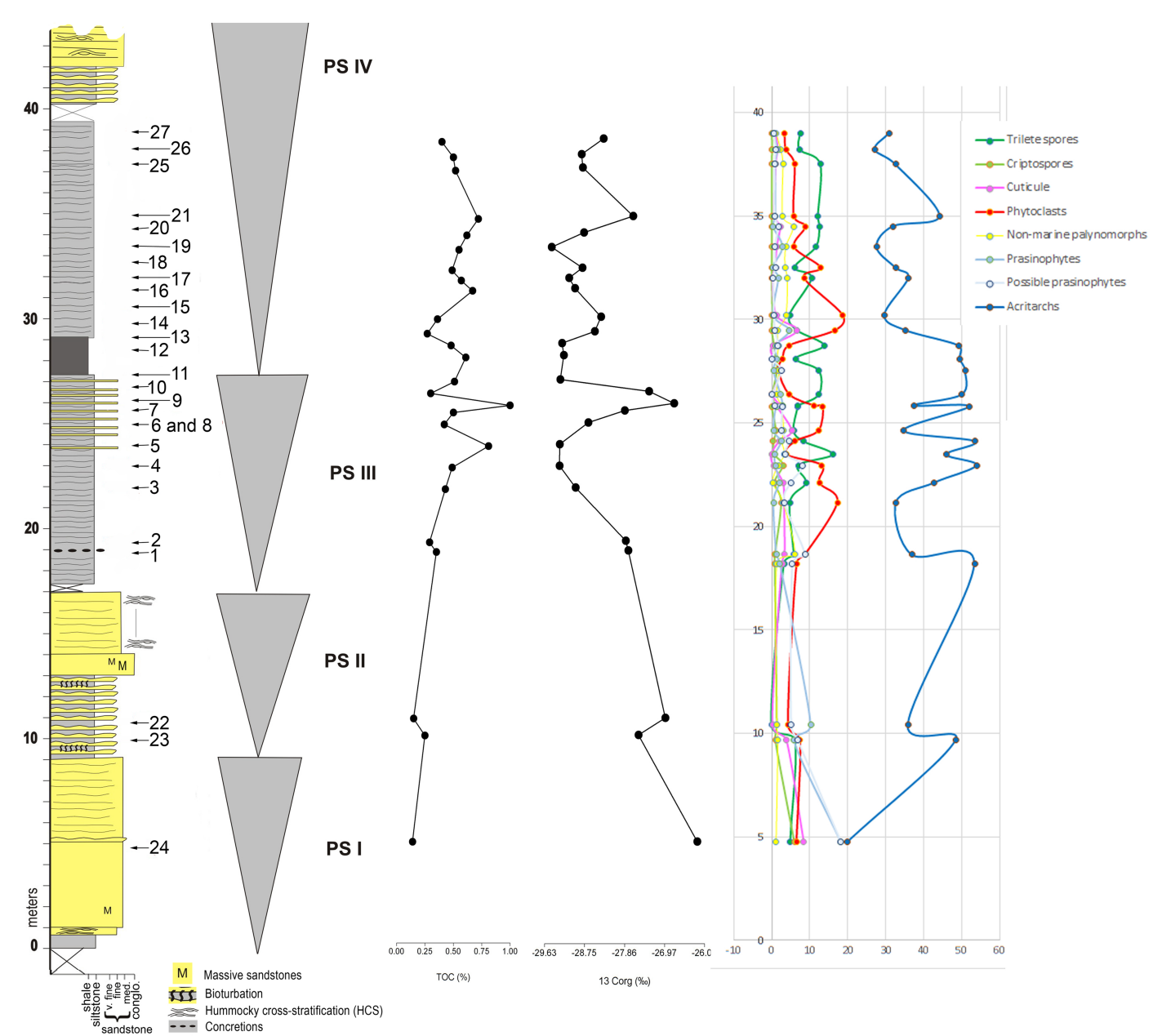
PS IV
PS III
PS II
PS I
meters
40
30
20
10
0
27
26
25
21
20
19
18
17
16
15
14
13
12
11
10
9
7
6 and 8
5
4
3
2
1
22
23
24
M
M
M
shale
siltstone
v. fine
fine
med.
conglo.
sandstone
Massive sandstones
Bioturbation
Hummocky cross-stratification (HCS)
Concretions
0.00
0.25
0.50
0.75
1.00
TOC (%)
-29.63
-28.75
-27.86
-26.97
13 Corg (‰)
Trilete spores
Criptospores
Cuticule
Phytoclasts
Non-marine palynomorphs
Prasinophytes
Possible prasinophytes
Acritarchs
-10
0
10
20
30
40
50
60

Figure 3

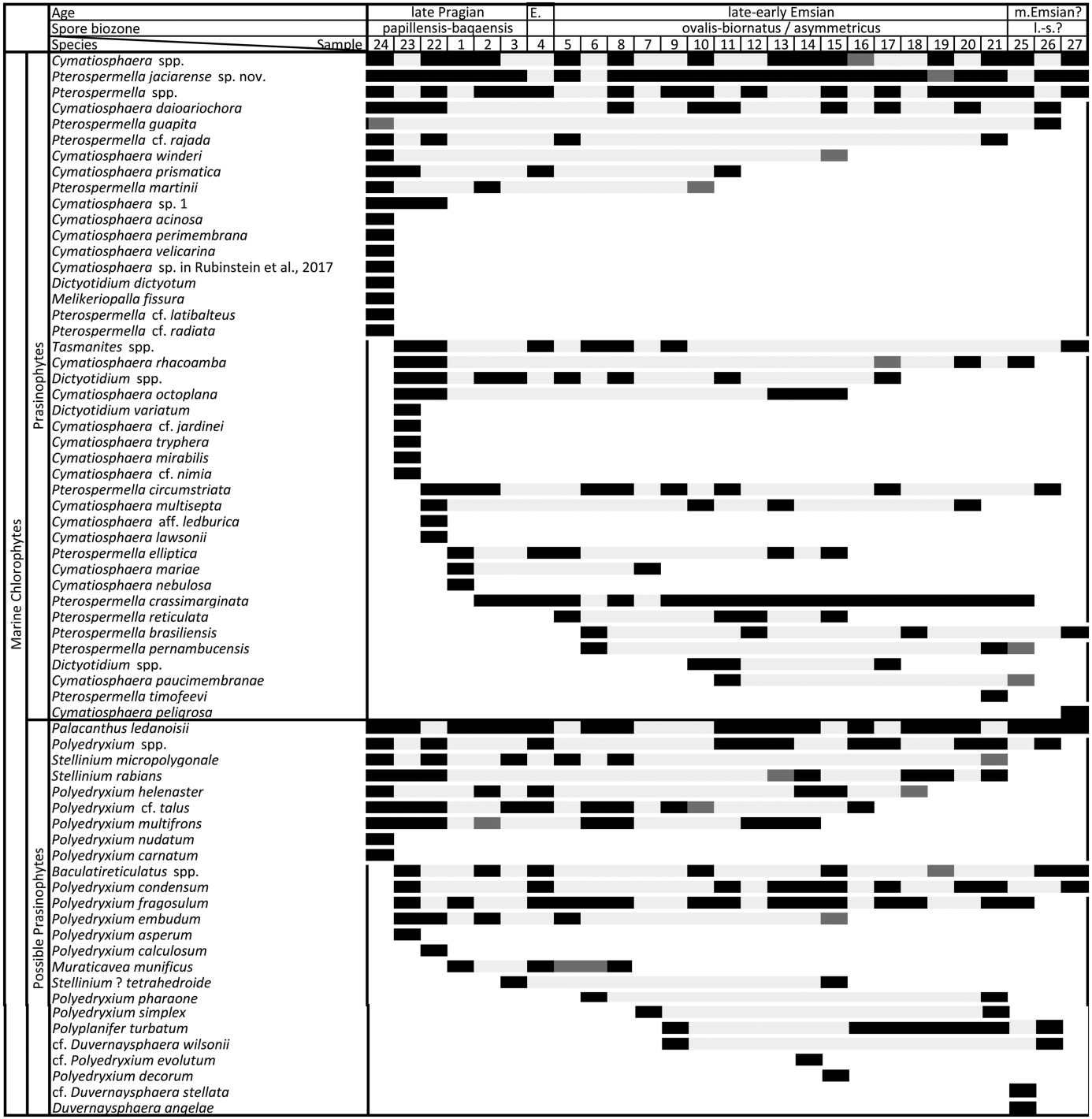
Age
late Pragian
E.
late-early Emsian
m.Emsian?
Spore biozone
papillensis-baqaensis
ovalis-biornatus / asymmetricus
l.-s.?
Species
Sample
24 23 22 1 2 3 4 5 6 8 7 9 10 11 12 13 14 15 16 17 18 19 20 21 25 26 27
Marine Chlorophytes
Prasinophytes
Possible Prasinophytes
Cymatiosphaera spp.
Pterospermella jaciarense sp. nov.
Pterospermella spp.
Cymatiosphaera daioariochora
Pterospermella guapita
Pterospermella cf. rajada
Cymatiosphaera winderi
Cymatiosphaera prismatica
Pterospermella martinii
Cymatiosphaera sp. 1
Cymatiosphaera acinosa
Cymatiosphaera perimembrana
Cymatiosphaera velicarina
Cymatiosphaera sp. in Rubinstein et al., 2017
Dictyotidium dictyotum
Melikeriopalla fissura
Pterospermella cf. latibalteus
Pterospermella cf. radiata
Tasmanites spp.
Cymatiosphaera rhacoamba
Dictyotidium spp.
Cymatiosphaera octoplana
Dictyotidium variatum
Cymatiosphaera cf. jardinei
Cymatiosphaera tryphera
Cymatiosphaera mirabilis
Cymatiosphaera cf. nimia
Pterospermella circumstriata
Cymatiosphaera multisepta
Cymatiosphaera aff. ledburica
Cymatiosphaera lawsonii
Pterospermella elliptica
Cymatiosphaera mariae
Cymatiosphaera nebulosa
Pterospermella crassimarginata
Pterospermella reticulata
Pterospermella brasiliensis
Pterospermella pernambucensis
Dictyotidium spp.
Cymatiosphaera paucimembranae
Pterospermella timofeevi
Cymatiosphaera peligrosa
Palacanthus ledanoisii
Polyedryxium spp.
Stellinium micropolygonale
Stellinium rabians
Polyedryxium helenaster
Polyedryxium cf. talus
Polyedryxium multifrons
Polyedryxium nudatum
Polyedryxium carnatum
Baculatireticulatus spp.
Polyedryxium condensum
Polyedryxium fragosulum
Polyedryxium embudum
Polyedryxium asperum
Polyedryxium calculosum
Muraticavea munificus
Stellinium ? tetrahedroide
Polyedryxium pharaone
Polyedryxium simplex
Polyplanifer turbatum
cf. Duvernaysphaera wilsonii
cf. Polyedryxium evolutum
Polyedryxium decorum
cf. Duvernaysphaera stellata
Duvernaysphaera angelae

Figure 4

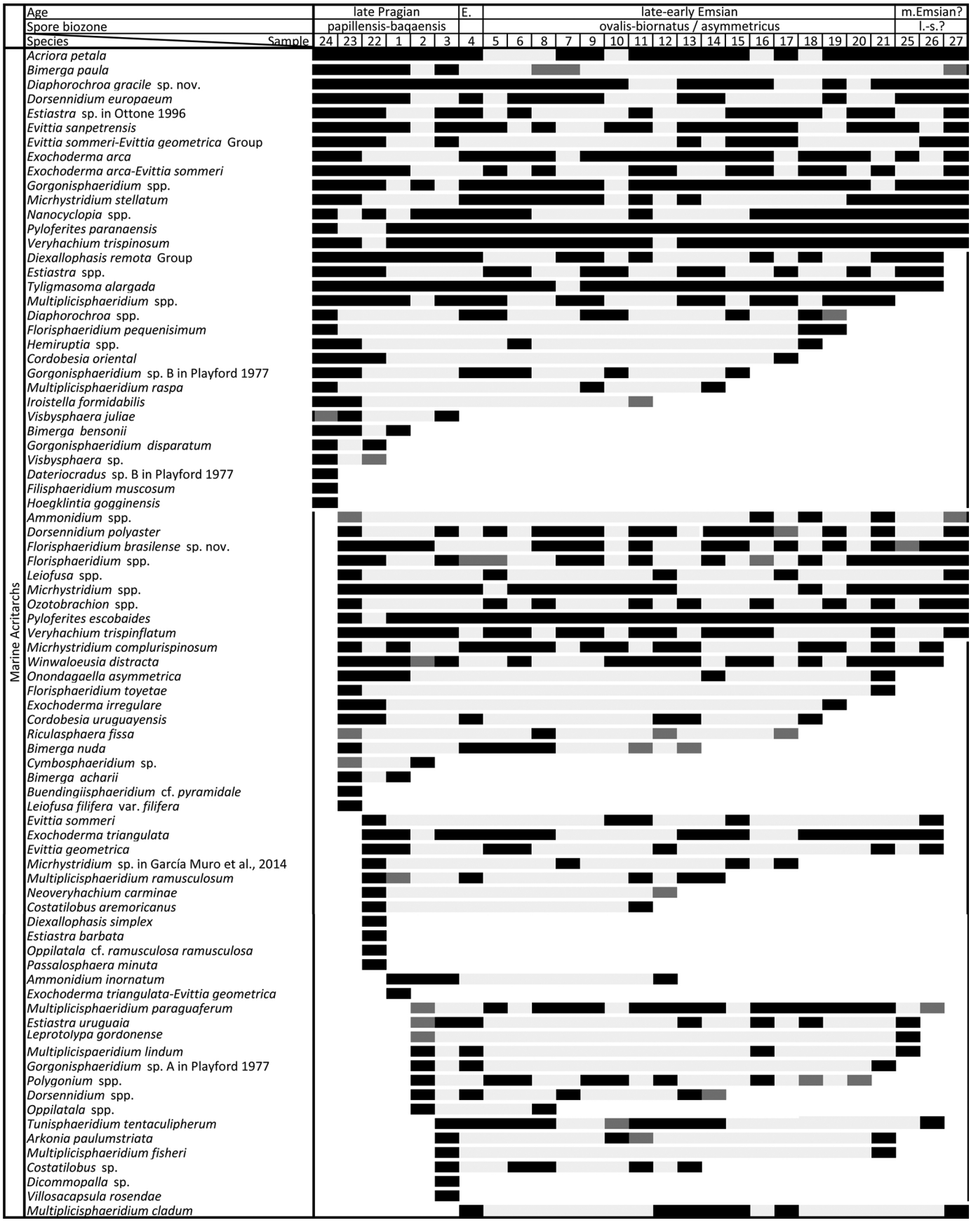
Age
late Pragian
E.
late-early Emsian
m.Emsian?
Spore biozone
papillensis-baqaensis
ovalis-biornatus / asymmetricus
l.-s.?
Species
Sample
24 23 22 1 2 3 4 5 6 8 7 9 10 11 12 13 14 15 16 17 18 19 20 21 25 26 27
Marine Acritarchs
Acriora petala
Bimerga paula
Diaphorochroa gracile sp. nov.
Dorsennidium europaeum
Estiastra sp. in Ottone 1996
Evittia sanpetrensis
Evittia sommeri-Evittia geometrica Group
Exochoderma arca
Exochoderma arca-Evittia sommeri
Gorgonisphaeridium spp.
Micrhystridium stellatum
Nanocyclopia spp.
Pyloferites paranaensis
Veryhachium trispinosum
Diexallophasis remota Group
Estiastra spp.
Tyligmasoma alargada
Multiplicisphaeridium spp.
Diaphorochroa spp.
Florisphaeridium pequenisimum
Hemiruptia spp.
Cordobesia oriental
Gorgonisphaeridium sp. B in Playford 1977
Multiplicisphaeridium raspa
Iroistella formidabilis
Visbysphaera juliae
Bimerga bensonii
Gorgonisphaeridium disparatum
Visbysphaera sp.
Dateriocradus sp. B in Playford 1977
Filisphaeridium muscosum
Hoegklintia gogginensis
Ammonidium spp.
Dorsennidium polyaster
Florisphaeridium brasilense sp. nov.
Florisphaeridium spp.
Leiofusa spp.
Micrhystridium spp.
Ozotobrachion spp.
Pyloferites escobaides
Veryhachium trispinflatum
Micrhystridium complurispinosum
Winwaloeusia distracta
Onondagaella asymmetrica
Florisphaeridium toyetae
Exochoderma irregulare
Cordobesia uruguayensis
Riculasphaera fissa
Bimerga nuda
Cymbosphaeridium sp.
Bimerga acharii
Buendingiisphaeridium cf. pyramidale
Leiofusa filifera var. filifera
Evittia sommeri
Exochoderma triangulata
Evittia geometrica
Micrhystridium sp. in García Muro et al., 2014
Multiplicisphaeridium ramusculosum
Neoveryhachium carminae
Costatilobus aremoricanus
Diexallophasis simplex
Estiastra barbata
Oppilatala cf. ramusculosa ramusculosa
Passalosphaera minuta
Ammonidium inornatum
Exochoderma triangulata-Evittia geometrica
Multiplicisphaeridium paraguaferum
Estiastra uruguaia
Leprotolypa gordonense
Multiplicispaeridium lindum
Gorgonisphaeridium sp. A in Playford 1977
Polygonium spp.
Dorsennidium spp.
Oppilatala spp.
Tunisphaeridium tentaculipherum
Arkonia paulumstriata
Multiplicisphaeridium fisheri
Costatilobus sp.
Dicommopalla sp.
Villosacapsula rosendae
Multiplicisphaeridium cladum

Figure 5

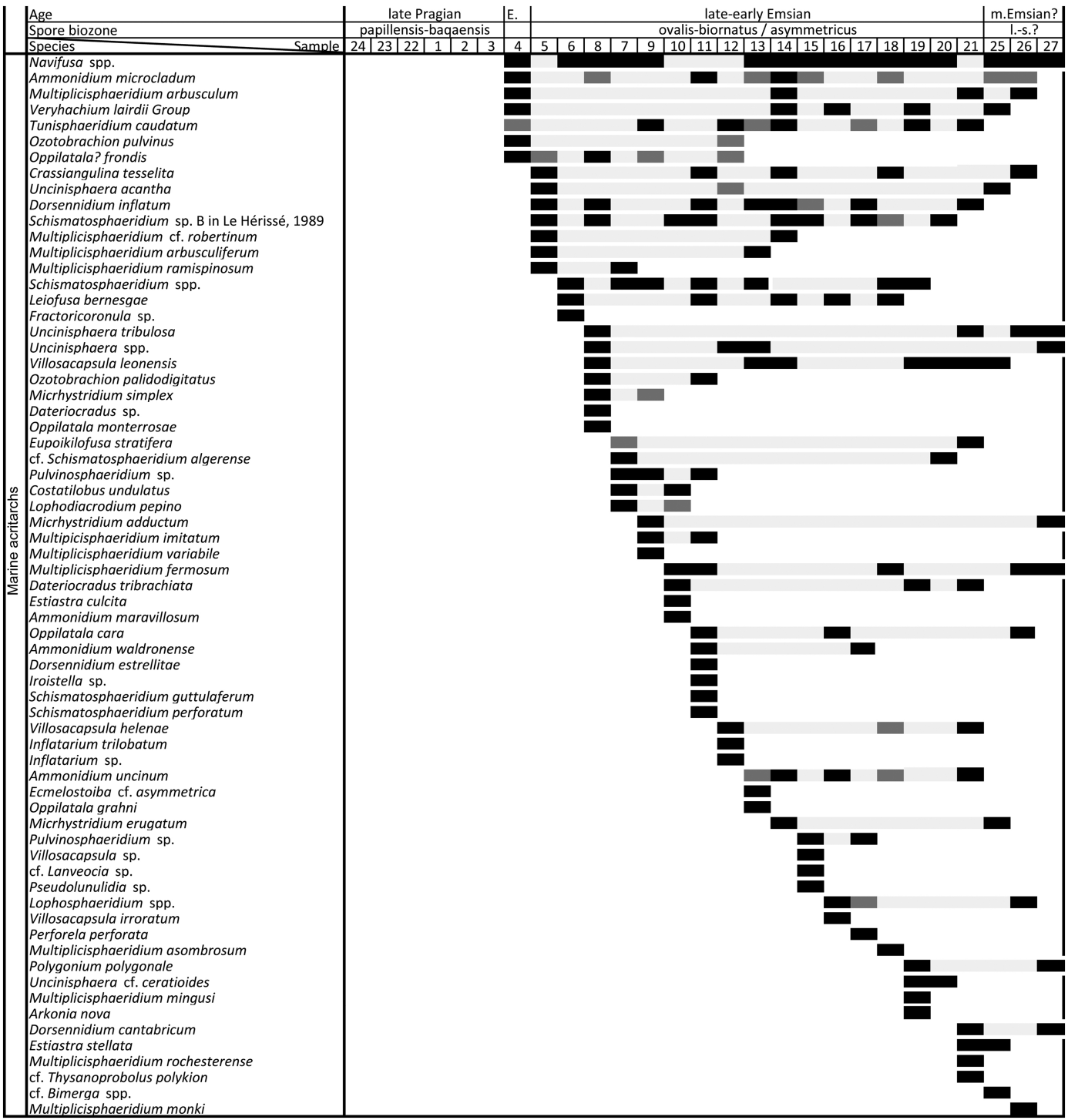
Age
late Pragian
E.
late-early Emsian
m.Emsian?
Spore biozone
papillensis-baqaensis
ovalis-biornatus / asymmetricus
l.-s.?
Species
Sample
24 23 22 1 2 3 4 5 6 8 7 9 10 11 12 13 14 15 16 17 18 19 20 21 25 26 27
Marine acritarchs
Navifusa spp.
Ammonidium microcladum
Multiplicisphaeridium arbusculum
Veryhachium lairdii Group
Tunisphaeridium caudatum
Ozotobrachion pulvinus
Oppilatala? frondis
Crassiangulina tesselita
Uncinisphaera acantha
Dorsennidium inflatum
Schismatosphaeridium sp. B in Le Hérissé, 1989
Multiplicisphaeridium cf. robertinum
Multiplicisphaeridium arbusculiferum
Multiplicisphaeridium ramispinosum
Schismatosphaeridium spp.
Leiofusa bernesgae
Fractoricoronula sp.
Uncinisphaera tribulosa
Uncinisphaera spp.
Villosacapsula leonensis
Ozotobrachion palidodigitatus
Micrhystridium simplex
Dateriocradus sp.
Oppilatala monterrosae
Eupoikilofusa stratifera
cf. Schismatosphaeridium algerense
Pulvinosphaeridium sp.
Costatilobus undulatus
Lophodiacrodium pepino
Micrhystridium adductum
Multipicisphaeridium imitatum
Multiplicisphaeridium variabile
Multiplicisphaeridium fermosum
Dateriocradus tribrachiata
Estiastra culcita
Ammonidium maravillosum
Oppilatala cara
Ammonidium waldronense
Dorsennidium estrellitae
Iroistella sp.
Schismatosphaeridium guttulaferum
Schismatosphaeridium perforatum
Villosacapsula helenae
Inflatarium trilobatum
Inflatarium sp.
Ammonidium uncinum
Ecmelostoiba cf. asymmetrica
Oppilatala grahni
Micrhystridium erugatum
Pulvinosphaeridium sp.
Villosacapsula sp.
cf. Lanveocia sp.
Pseudolunulidia sp.
Lophosphaeridium spp.
Villosacapsula irroratum
Perforela perforata
Multiplicisphaeridium asombrosum
Polygonium polygonale
Uncinisphaera cf. ceratioides
Multiplicisphaeridium mingusi
Arkonia nova
Dorsennidium cantabricum
Estiastra stellata
Multiplicisphaeridium rochesterense
cf. Thysanoprobolus polykion
cf. Bimerga spp.
Multiplicisphaeridium monki

Figure 6

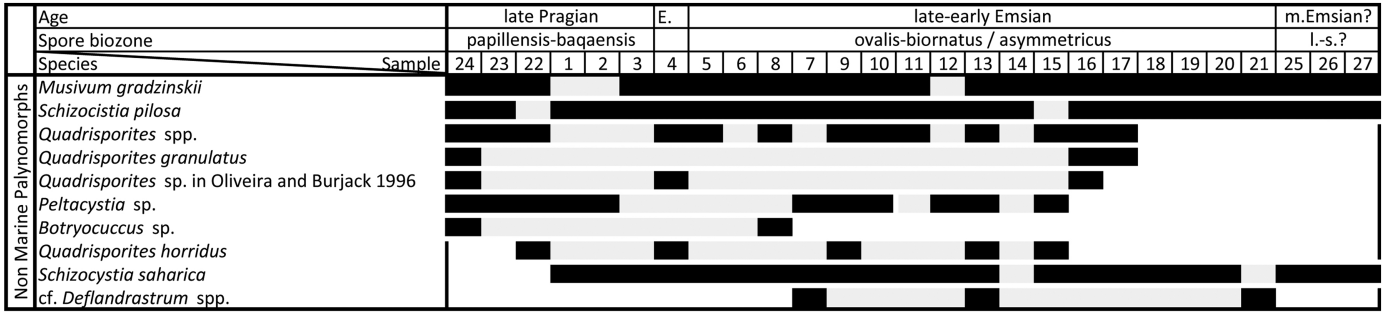
Age
late Pragian
E.
late-early Emsian
m.Emsian?
Spore biozone
papillensis-baqaensis
ovalis-biornatus / asymmetricus
l.-s.?
Species
Sample
24 23 22 1 2 3 4 5 6 8 7 9 10 11 12 13 14 15 16 17 18 19 20 21 25 26 27
Non Marine Palynomorphs
Musivum gradzinskii
Schizocistia pilosa
Quadrisporites spp.
Quadrisporites granulatus
Quadrisporites sp. in Oliveira and Burjack 1996
Peltacystia sp.
Botryocuccus sp.
Quadrisporites horridus
Schizocystia saharica
cf. Deflandrastrum spp.

Figure 7

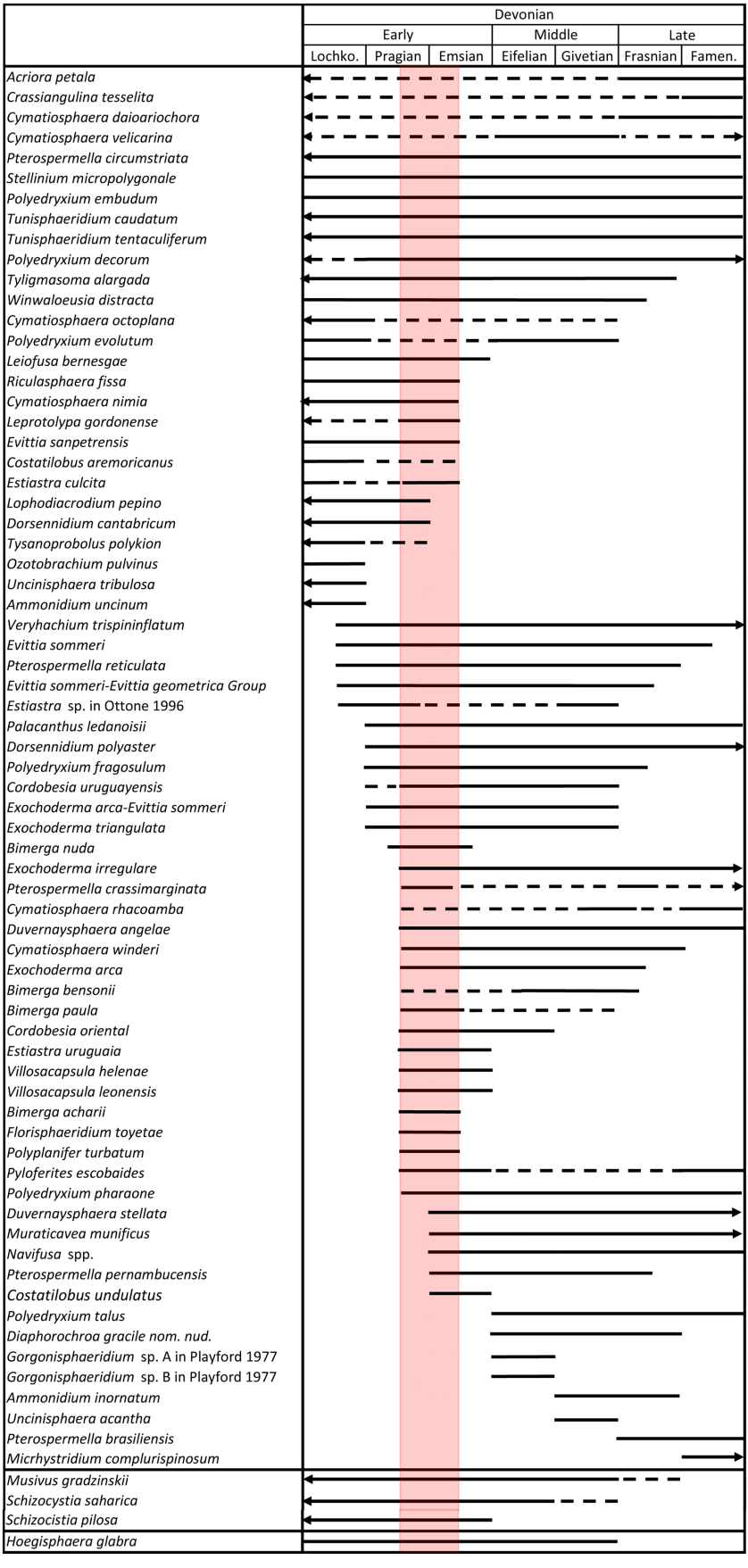
Devonian
Early
Middle
Late
Lochko.
Pragian
Emsian
Eifelian
Givetian
Frasnian
Famen.
Acriora petala
Crassiangulina tesselita
Cymatiosphaera daioariochora
Cymatiosphaera velicarina
Pterospermella circumstriata
Stellinium micropolygonale
Polyedryxium embudum
Tunisphaeridium caudatum
Tunisphaeridium tentaculiferum
Polyedryxium decorum
Tyligmasoma alargada
Winwaloeusia distracta
Cymatiosphaera octoplana
Polyedryxium evolutum
Leiofusa bernesgae
Riculasphaera fissa
Cymatiosphaera nimia
Leprotolypa gordonense
Evittia sanpetrensis
Costatilobus aremoricanus
Estiastra culcita
Lophodiacrodium pepino
Dorsennidium cantabricum
Tysanoprobolus polykion
Ozotobrachium pulvinus
Uncinisphaera tribulosa
Ammonidium uncinum
Veryhachium trispininflatum
Evittia sommeri
Pterospermella reticulata
Evittia sommeri-Evittia geometrica Group
Estiastra sp. in Ottone 1996
Palacanthus ledanoisii
Dorsennidium polyaster
Polyedryxium fragosulum
Cordobesia uruguayensis
Exochoderma arca-Evittia sommeri
Exochoderma triangulata
Bimerga nuda
Exochoderma irregulare
Pterospermella crassimarginata
Cymatiosphaera rhacoamba
Duvernaysphaera angelae
Cymatiosphaera winderi
Exochoderma arca
Bimerga bensonii
Bimerga paula
Cordobesia oriental
Estiastra uruguaia
Villosacapsula helenae
Villosacapsula leonensis
Bimerga acharii
Florisphaeridium toyetae
Polyplanifer turbatum
Pyloferites escobaides
Polyedryxium pharaone
Duvernaysphaera stellata
Muraticavea munificus
Navifusa spp.
Pterospermella pernambucensis
Costatilobus undulatus
Polyedryxium talus
Diaphorochroa gracile nom. nud.
Gorgonisphaeridium sp. A in Playford 1977
Gorgonisphaeridium sp. B in Playford 1977
Ammonidium inornatum
Uncinisphaera acantha
Pterospermella brasiliensis
Micrhystridium complurispinosum
Musivus gradzinskii
Schizocystia saharica
Schizocistia pilosa
Hoegisphaera glabra

Figure 8